CONSTRUCTION AND COMPARISON OF THE EFFICIENCY OF DIFFERENT SELECTION INDICES FOR MALABARI GOATS

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MANNUTHY, THRISSUR-680651

KERALA, INDIA

2009

DECLARATION

I hereby declare that this thesis, entitled "**CONSTRUCTION AND COMPARISON OF THE EFFICIENCY OF DIFFERENT SELECTION INDICES FOR MALABARI GOATS"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Mannuthy **RANI ALEX**

CERTIFICATE

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ACKNOWLEDGEMENT

Here I wish to acknowledge the support of many respected persons who provided me with enchanting inspirations, enduring motivations and invaluable advices in successfully completing my research work. I have no hesitation whatsoever, to say that I would not have been able to complete the work without thee guidance of those whom I could remind only with great reverence and gratitude.

To a great extend, I am indebted to my guide and Chairman of the Advisory Committee, ***Dr. K. C, Raghavan****, Professor, Centre for Advanced Studies in Animal Genetics and Breeding for his valuable guidance, critical suggestions, scholarly advice, generous support and timely help in all the possible ways during the entire period of my study and research work.*

I am very thankful to ***Dr. K.V. Raghunandanan****, Director, Centre for Advanced Studies in Animal Genetics and Breeding and Member of the Advisory Committee, for his words of inspiration, kindness and professional guidance during the entire period of research.*

There is no word to pay my gratefulness to ***Dr. A.P. Usha,*** *Professor, Department of Animal Breeding and Genetics, College of Veterinary and Animal Sciences, Pookot, Wyanad and Member of the Advisory Committee, for her wholehearted co-operation, incessant encouragement and affection.*

I owe my sincere thanks to ***Dr. K. A. Mercey,*** *Associate Professor, Department of Statistics and Member of the Advisory Committee, for her wholehearted help, genuine support and suggestions offered for statistical analysis part of this work.*

I am obliged, thankful and grateful to ***Dr. Stephen Mathew, Dr. T.V. Aravindakshan****, Professors, Centre for Advanced Studies in Animal Genetics and Breeding and* ***Dr. K.A. Bindu,*** *Associate Professor, Department of Animal Breeding, Genetics and Biostatistics, for all the help, inspirations and co-operations rendered from time to time.*

I am extremely grateful to ***Dr. Radhika G. and Dr. Naicy Thomas,*** *Assistant Professor, Department of Animal Breeding, Genetics and Biostatistics, for their help.*

The assistance and encouragement provided by my colleagues, ***Dr. Lali F. Anand*** *and* ***Dr. Rajendra Ashok Bhosale,*** *are acknowledged to the full worth.*

I am obliged and grateful to my respected and reverent seniors, **Dr. Arpitha Nair, Dr. Jimcy Joseph and Dr. Rojan P.M.** whose affectionate friendship, mental support and timely advice helped me in overcoming the hardships faced during the period of study and research work.

I express my heartfelt thanks to my junior colleagues **Dr. Muhammed E.M.**, **Dr. Remya John, Dr. Sudhina, K,** and **Dr. Aparna Sankar** for their help and cooperation. I treasure the generous help, concern, encouragement and moral support rendered by **Mr. Arun Raveendran** and **Miss. Simi R.S.** during the research work.

I always remember with gratitude the help rendered by **Dr. Ayub A.**during the research work. It is pleasures to greatefully acknowledge the assistance and lively support of all my friends at COVAS. My sincere thanks to **Dr. Sani Thomas, Dr. Asha Antony, Dr. Jini George and Dr. Indu K** for their help and cooperation. I also express my thanks to my friends, **Sreelakshmi M., Sree parvathy M., Sreelakshmi C.M., Sameera S. and Keerthy A.J.** for supporting me all the time

I am thankful to my friend, **Dr. Siju Susan Jacob** for providing me some key research articles for my work.

The persistent encouragement and support rendered by my friend, **Dr.Avinash** throughout the entire period of research work is acknowledged with appreciation.

I express my sincere thanks to all **staff members of the Department of Animal Breeding, Genetics and Biostatistics.**

I am grateful to **Dr.E.Nanu,** Dean, College of Veterinary and Animal Sciences, Mannuthy and **Kerala Agricultural University** for the facilities provided for this research work.

No words can implicitly express the deep gratitude to my **Parents, brothers, sister in law, Anna and Akku mol** for their affection, encouragement, prayers and blessings, which helped me a lot to overcome various hardships with flying colours. I owe very much to them.

Lastly, to the God Almighty, for all he has given and…………

Rani Alex

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INTRODUCTION

1. INTRODUCTION

The goat is the earliest domesticated ruminant and has served mankind earlier and longer than cattle and sheep. Goats have distinct social, economical, managerial and biological advantages over other livestock species. They significantly contribute to the agrarian economy and play a very vital role in the livelihood security of small and marginal farmers and landless labourers especially in the arid, semi-arid and mountainous regions of the country. Thus the goat has been appropriately termed “the poor man’s cow” and certainly no better designation could be found to express the position of this useful creature amongst our domestic animals.

India's vast genetic resources in goats is reflected by the availability of about 20 breeds of goats that have evolved naturally through adaptation to different agro-ecological conditions. Indian goat breeds exhibit enormous variations in growth, fecundity, production of meat, milk and fiber, disease resistance and heat tolerance.

Goat production in Kerala is mainly centred on its native breed Malabari (or Tellichery), which is believed to have originated centuries ago by mixing of native feral goats with Arab, Surti and Mesopotamian goats along with the native goats of the Western Coast. It is well known for high prolificacy, milk yield, excellent growth rate and adaptability to the hot humid conditions prevalent in the state.

The breeding objective in any livestock species is to increase profit by improving the production efficiency. To improve the low productivity of the indigenous breed, elite germplasm should be used for breeding purposes. So deciding which are the most suited individuals to select as parents of the next generation is a critical issue for every animal breeder.

Individual selection is the simplest form of selection in which individuals with the better phenotypic value for a trait are selected with the objective of increasing the mean value of the trait in future generations. But the relative economic merit of individuals in a breed or variety will often depend on the better performance in different traits. Therefore, multi-trait selection is always preferred over single trait selection. When improvement is desired for several traits that may differ in variability, heritability, economic importance and in the correlation among phenotypes and genotypes, index selection is more effective than independent culling levels or sequential selection (Hazel and Lush, 1942). Selection index is a single numerical expression intended to predict with maximum accuracy the net breeding value of individuals or populations considering all traits in which improvement or continued superiority is desired. Placing breeding objectives into a mathematical form on a sound economic basis is the key to integrate modern developments in animal breeding into more purposeful industrial programs.

In order to have the maximum overall genetic improvement of Malabari goats, an index method of selection utilizing various growth and milk production traits is always advantageous. So comparison of various selection indices and identifying more efficient ones among them which are suitable under the prevailing conditions would certainly help future selection procedures for Malabari goats. Keeping this in view, this study was undertaken with the following objectives:

1) Develop different selection indices for Malabari goats under field conditions.

2) Compare the efficiencies of different selection indices and to select the best index for genetic improvement of Malabari goats.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Goat rearing is of great importance in rural Indian households and plays a major role for the sustenance of small and marginal farmers and landless agricultural labourers. The Indian subcontinent has about 20 well-characterized goat breeds, which vary in their genetic potential for the production of milk, meat and fibre, disease resistance, heat tolerance and fecundity (Joshi *et al.*, 2004). Goat production in Kerala is mainly centred on its native breed Malabari (Tellichery), which is Kerala's prestigious goat breed and is famous for its prolificacy. It is a dual purpose breed reared for both meat and milk (Acharya, 1982). Selective breeding is the recommended method for the improvement of this breed. Multiple trait index selection is found to be more effective than other methods since it considers more traits that may differ in variability, heritability, economic importance and in the correlation among their phenotypes and genotypes (Hazel *et al.*, 1994). In this work, aimed at formulation and comparison of different indices for selection of males and females of Malabari goats, the available literature on Indian breeds of goats and most relevant literature on other species are reviewed under the following heads:

2.1 Body weights at different ages
2.2 Body measurements at various ages
2.3 Milk production
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2.1 BODY WEIGHTS

Body weight, which is an indication of growth rate of animals, is one of the important criteria considered in the selection index programme (Lawrence and Fowler, 1997).

2.1.1 Body Weights up to Six Months of Age

Growth rate up to six months of age is an important factor, which gives an indication about subsequent performance of the animal. The available literature on body weights of Indian breeds of goats are presented in table 2.1.

Table 2.1 Body weights (kg) of different Indian breeds of goats at below one, three and six months of age

Breed	Below one month	3 months	6 months	Reference
Sirohi	2.88±0.03	12.58±0.17	18.29±0.22	Mehta *et al.*(1997)
Marwari	2.38±0.15	9.99±1.45	15.69±1.12	Patel *et al.* (1999)
Parbatsar	3.00±0.25	14.36±0.945	18.26±0.77	
Jamunapari	2.79±0.04	9.12±0.14	13.14±0.21	Roy *et al.*(2003)
Marwari	3.05±0.05	11.35±0.17	14.94±0.21	Rai *et al.* (2004)
Gaddi females	4.06±0.30	14.30±0.50	18.50±0.70	Gupta *et al.* (2005)
males	4.30±0.80	14.70±0.70	19.10±0.60	
Jamunapari	2.93±0.04	14.30±0.17	19.66±0.30	Anon.(2005)
Black Bengal	1.25	5.25	7.87	
Ganjam Males	2.89±0.01	8.37±0.03	12.13±0.11	

Females	2.46±0.27	7.36±0.22	11.02±0.04	
Sirohi	3.07±0.04	11.73±0.16	16.74±0.28	
Barbari	1.86±0.01	7.63±0.07	12.02±0.11	
Sirohi	2.16±0.05	10.84±0.23	15.24±0.28	Sharma and Pathodiya (2007)
Malabari	2.26±0.12	9.70±0.42	14.05±0.86	Anon.(2007)

2.1.2 Factors Affecting Body Weights

Different genetic and non-genetic factors affect body weight at different ages in goats. Knowledge of these factors will help to formulate the breeding programme by taking into consideration the variation caused by these factors (Eltawil *et al.*, 1970).

2.1.2.1 Effect of Centre

Bindu (2006) reported that the mean birth weight of Malabari goat in kilograms in Tanur, Thalassery and Badagara regions of northern Kerala were 1.73± 0.04, 1.88±0.03 and 1.86±0.05 kg respectively. At three months, the values were 8.83 ±0.30, 10.02±0.24 and 9.52±0.26 kg and at six months of age the weights were 17.83 ±1.54, 21.00±0.47 and 21.36±0.55 kg respectively. The goats of Thalassery and Badagara regions were found to be heavier when compared to Tanur.

Sghaier *et al.* (2007) reported the significant effect of ecological zone in indigenous kids' growth in Pastoral mode in Tunisian arid region.

Centre is reported to have significant effect on body weight from birth to one year of age. Animals born in Tellichery had lower birth weight than those reported for Tanur and Badagara regions. But Tanur animals were recording lower values at all other ages (Anon., 2007).

2.1.2.2 Effect of Sex

Raghavan (1980) observed that there was significant difference between male and female kids in birth weight in both Saanen × Malabari and Alpine × Malabari, but it was non-significant in case of Malabari. At one and four months of age, it was significant for only Saanen × Malabari. Sex affected body weight in all genetic groups.

Mukundan *et al.* (1983) reported significant effect of sex on pre-weaning body weights in Malabari goats and its Saanen half-bred.

Salah *et al.* (1989) reported that body weight was strongly affected by sex at birth, three, six, nine and twelve months of age in the case of Aardi kids of Saudi Arabia.

According to Saxena *et al.* (1990) males were significantly heavier than females at birth in Jamunapari kids.

Tyagi *et al.* (1992) reported that the effect of sex was significant on post weaning growth in Jakhrana goats and male kids weighed heavier during 3-12 months of age.

Menon (1994) reported that in Malabari goats, sex had no effect on body weights at birth, three, six, nine and twelve months of age; whereas in Alpine × Malabari, sex had a significant effect on the body weights in all the age groups studied.

Singh *et al.* (2000a) reported that in Beetal half-bred kids, the variation in birth weight due to sex was significant. Male kids were significantly heavier than females and a similar trend was observed for body weight at three and six months of age, though the differences were not significant statistically.

Zhou *et al.* (2003) revealed that males had heavier body weight at birth, weaning, and one year of age than females in inner Mongolia Cashmere goats in China.

Kosum *et al.* (2004) reported that effect of sex was significant on birth weight and weaning weight of Saanen, Bornova and Saanen×Kilis goats.

Liu *et al.* (2005) observed that body weights at birth, weaning, 12 and 18 months were significantly affected by sex.

Sghaier *et al.* (2007) reported that after birth, differences in kid's weight were remarkably significant for the two sexes.

According to Thiruvenkadan *et al.* (2008), the sex of the kids had highly significant effect on birth weight of Tellicheri kids.

2.1.2.3 Effect of Type of Birth

Raghavan (1980) reported a significant effect of litter size on birth and one month weight in Malabari, Alpine× Malabari and Saanen ×Malabari. Kids born as singles had higher body weight than twins and triplets.

Khan and Sahni (1983) observed that type of birth had significant effect on body weights and body measurements at birth, one, two and three months of age in Jamunapari goats. Kids born as singles weighed 12% more than the twins at birth.

Salah *et al.* (1989) reported that single born Aardi kids were superior in the weights at birth and later ages to twin born kids except at one year age.

Saxena *et al.* (1990) revealed that in Jamunapari kids, the effect of type of birth on birth weight was significant and singles were significantly heavier than twins.

Tyagi *et al.* (1992) reported that litter size did not affect the post-weaning body growth in Jakhrana goats and there was significant difference in body weight between singles and twins only at birth.

According to Menon (1994) type of birth had no significant effect on body weight of both Malabari and Alpine ×Malabari goats at birth, three, six, nine and twelve months of age.

Raghavan *et al.* (1999) reported that type of birth exerted a highly significant effect on birth weight of Malabari kids. Singles had highest birth weight of 1.830±0.078 kg followed by twins with a mean of 1.585±0.7459 kg.

Type of birth had significant effect on body weight at birth, three and six months of age in Beetal half-bred kids. The kids born as singles were significantly heavier at birth than those born as twins and triplets. But at three and six months, the single born kids were significantly heavier than those of twin birth where as triplets did not differ significantly from singles and twins (Singh *et al.*, 2000a).

Zhou *et al.* (2003) reported that type of birth had significant effects on body weights at birth, weaning and one year of age in inner Mongolia Cashmere goats in China.

According to Kosum *et al.* (2004) there was significant effect of type of birth on birth weight and weaning weight for Saanen, Bornova and Saanen ×Kilis goats.

Liu *et al.* (2005) revealed that type of birth had significant effect on body weights at different ages in Angora goats.

Sghaier *et al.* (2007) revealed that the difference between singles and multiples was not clearly showed till third month and thereafter there was significant difference between body weights in indigenous kids reared under Pastoral mode in Tunisian Arid region.

McManus *et al.* (2008) reported that type of birth did not affect pre and post- weaning growth rates. But it had significant effect on birth weight in Saanen, Alpine and Toggenburg goats in the Federal district, Brazil.

Type of birth had significant effect on birth weight of Tellichery kids and the kids born as singles were heavier than those born as multiples (Thiruvenkadan *et al.*, 2008).

2.1.2.4 Effect of Year of Birth

Mukundan *et al.* (1983) noticed significant effect of year of birth on pre- weaning body weights in Malabari goats and its Saanen halfbreds.

Malik *et al.* (1986) reported that year of birth had significant effect on pre- weaning body weights in Beetal, Black Bengal and their crosses. The kids born during 1982 were heavier at 30, 60 and 90 days of age than those born during previous years.

Roy *et al.* (2001) reported that year of birth had significant effect on body weights at three and six months of age in Jamunapari goats.

Kosum *et al.* (2004) reported that year of birth had significant effect on birth and weaning weight in Saanen, Bornova and Saanen ×Kilis goats.

Rai *et al.* (2004) reported that year of birth showed a significant effect on birth weight and weaning weight of Marwari kids but they did not affect post-weaning weight.

Sghaier *et al.* (2007) reported that year of birth had significant effect upon kids' growth. At early ages the effect of year was highly significant and this effect became higher with the kid's age, as the nutrient requirement was increasing, in indigenous kids under Pastoral mode in Tunisian arid region.

McManus *et al.* (2008) reported that the year of kidding had significant effect on birth weight but not on weaning weight in Saanen, Alpine and Toggenburg goats in the Federal district of Brazil.

2.1.2.5 Effect of Season

Raghavan (1980) reported no significant difference in birth weight according to season of birth in Malabari and its crossbreds with Alpine and Saanen. However Malabari and Alpine × Malabari kids born in winter registered higher birth weight than the kids born in summer and rainy season. He also observed a significant effect of season of birth on at fourth and twelfth months body weight.

Mavrogenis (1984a) observed a significant effect of season of birth on birth weight, weaning weight and 140 days weight in Damascus goats.

According to Malik *et al.* (1986), season of birth affected body weight up to 60 days of age. Kids born during February-April had higher mean birth weight than those born during September- November and maintained their superiority up to second month in Beetal and Black Bengal kids and their crosses.

Salah *et al.* (1989) reported that spring born kids of Aardi breed had higher weights at birth and later ages than winter and fall born ones. At birth, three, six, nine and twelve months, the weights of fall born were higher than that for winter born ones. However, all these season differences were not significant.

Tyagi *et al.* (1992) reported the effect of season was significant for body weight at sixth and ninth months of age in Jakhrana goats.

According to Menon (1994), season of birth had no significant effect on the body weights at birth, third, sixth, ninth and twelfth months of Malabari goats and at birth and three months of age for Alpine ×Malabari. But in Alpine × Malabari, season of birth had a significant effect at sixth, ninth and twelfth months body weight. Kids born in monsoon weighed heavier than those born in non-monsoon period.

According to Raghavan *et al.* (1999), season of kidding was found to be non- significant on average birth weight of Malabari kids.

Singh *et al.* (2000a) reported that in Beetal half bred kids, body weight at birth, third and sixth months of age and gain in weight in these periods were significantly affected by season of birth.

Season of birth was found to be a significant source of variation for birth weight in Marwari kids. Spring born kids showed a higher weight than those born in winter (Rai *et al.*, 2004).

Thiruvenkadan *et al.* (2008) observed that season had no significant effect on the birth weight of Tellichery kids and the kids born during winter were of higher birth weight than those born during summer.

2.2 BODY MEASUREMENTS

Body measurements are believed to be good indicators of body weight and hence different body measurements *viz.*, body length, height at withers and chest girth were used for selection of goats (Lawrence, and Fowler, 1997).

2.2.1 Body Measurements up to Six Months of Age

Kumar *et al.* (1992) reported that the overall mean body length, height at withers and chest girth at birth for Jamunapari goats were 32.21±0.24, 34.93±0.25 and 32.07±0.28 cm respectively. At three months of age these measurements were

45.96±0.58, 47.74±0.68 and 44.91±0.47 cm respectively. The mean body length, height at withers and chest girth at six months of age were 52.27±0.71, 54.47±0.84 and 50.68±0.86 cm respectively.

Menon (1994) reported that the mean length of Malabari goats in farm conditions at birth, three and six months of age were 26.01±0.06, 42.35±0.06 and 50.06±0.48 cm respectively. The mean value of girth at birth, three and six months of age were 28.23±0.08, 42.18±0.46 and 49.18±0.09 cm respectively. The height at withers at birth, three and six months of age were 30.24±0.10, 42.28±0.90 and 50.60±0.28 cm respectively.

Karna *et al.* (2001) reported that the mean body length, withers height and chest girth at birth for Chegu kids were 32.74±0.65, 29.33±0.13 and 31.93±0.20 cm respectively.

Tomar *et al.* (2001) reported that the overall mean body height, body length and chest girth at birth for Sirohi goats were 34.77±0.25, 31.07±0.22 and 30.86±0.27 cm respectively. At three months, the mean of these body measurements were 50.02±0.51, 47.38±0.48 and 48.01±0.40 cm respectively. The mean of body height, body length and heart girth at six months of age were 57.14±0.70, 55.02±0.67 and 56.35±0.71 cm respectively.

Das *et al.* (2002) reported that the mean body length, height at withers and heart girth at six months of age were 43.7±0.3, 43.4±0.3 and 45.2±0.3 cm respectively for Assam local and crossbred goats.

Ambhore *et al.* (2003) reported that mean value of different morphometric traits of Berari male goats like body length, height at withers and heart girth as 45.77±0.77, 54.00±0.43 and 56.88±0.35 cm respectively.

Gupta *et al.* (2005) reported that average chest girth for Gaddi males at birth, three and six months of age were 33.5±0.2, 49.3±0.5 and 55.3±1.0 cm respectively. The average body length for male and female were 34.5±0.5, 53.3±1.0 and 60.0±0.8 and 35.3±1.0, 52.0±0.9 and 59.0±1.0 cm respectively. The height at withers for the same age groups for male and female were 36.0±0.8, 51.4±0.2 and 56.5±1.1 and 34.9±1.0, 49.9±0.9 and 54.8±0.5 cm respectively

The mean heart girth of Malabari goats at birth, three and six months were 32.36±0.22, 47.58±0.25 and 56.63±0.33 cm respectively. The corresponding values for body length were 30.69±0.23, 44.70±0.20 and 53.10±0.32 cm respectively (Anon., 2007).

According to Verma *et al.* (2007), the mean value of body length, height at withers and chest girth at one month of age were 45.36±0.81, 46.35±0.93 and 44.37±0.98 cm respectively. The mean body length, height at withers and chest girth for males were 57.92±1.62, 60.71±1.49 and 57.15±1.38 cm and for females it was 56.38±1.63, 59.18±1.17 and 55.27±0.99 cm respectively. The mean body length, height at withers and chest girth at six months of age were 65.51±1.04, 72.08±0.96 and 65.33±1.83 cm for males and 63.33±1.12, 63.92±1.12 and 57.58±0.17 cm for females respectively.

2.2.2 Factors Affecting Body Measurements

Different factors cause variation in body measurements in goats.

2.2.2.1 Effect of Centre

Significant difference between populations of different areas in body measurements at different ages were reported in Malabari goats (Anon., 2007).

2.2.2.2 Effect of Sex

Karna *et al.* (2001) reported that there were non-significant differences between body measurements like body length, withers height and chest girth at birth between male and female kids.

Tomar *et al.* (2001) reported that sex of the kid had a highly significant effect on almost all body measurements like body height, body length and heart girth at birth, three and six months of age in Sirohi goats except body length at three months. Males measured higher than females at all stages of measurements.

Singh (2002) reported that the variation in height at withers due to sex was significant for Black Bengal and its halfbreds with Jamunapari and Beetal. But sex had no significant effect on body length and heart girth.

According to Das *et al.* (2002), sex of the kid had a significant effect on body length and height at withers at six months of age but the heart girth was not affected at six months of age by sex in Assam local and crossbred goats.

Liu *et al.* (2005) reported that sex of the kid had a significant effect on body length and height at withers in Angora goats but it had no effect on chest girth and females were larger than males for all measurements except height at withers.

2.2.2.3 Effect of Type of Birth

According to Tomar *et al.* (2001), the effect of type of birth was highly significant on all body measurements like body height, body length and heart girth at birth, three and six months of age in Sirohi goats. Single born kids recorded larger measurements as compared to kids born as twins.

Body measurements at six months of age were apparently higher in kids born as singles than in multiples in Assam local and crossbred goats. But the variations in body measurements were found to be significant only for body length and heart girth but not for height at withers (Das *et al.*, 2002).

Singh (2002) reported that the effect of type of birth was significant on body measurements like body length, height at withers and heart girth. The body biometrics of single born kids was significantly higher than twins and triplet births in Black Bengal and its halfbreds with Jamunapari and Beetal.

Liu *et al.* (2005) reported that type of birth had significant effect on height at withers and chest girth but not on body length in Angora goats.

2.2.2.4 Effect of Year of Birth

Tomar *et al.* (2001) reported that the effect of year of kidding was highly significant on most of the body measurements like body height, body length and heart girth at birth, three and six months of age except body length at six months while it was non-significant on body height at birth in Sirohi goats.

Karna *et al.* (2001) revealed that there was a significant effect of year of birth on body measurements at birth in Chegu goats. The mean body length, height at withers and chest girth of the kids born in 1978 were significantly higher than all other years.

Liu *et al.* (2005) reported that year of birth had a significant effect on body length, height at withers and chest girth.

2.2.2.5 Effect of Season

Karna *et al.* (2001) reported a significant effect of season of birth on body length at birth in Chegu goats whereas non-significant effect was noted in the case of height at withers and chest girth.

According to Das *et al.* (2002), season exerted significant influence on all the body measurements at six months of age in Assam local and crossbred goats. The kids born during post-monsoon season had the highest body measurements. Kids born in winter had significantly lower mean body length than those born in other seasons.

Singh (2002) reported that season of birth had a significant effect on heart girth of Black Bengal and its halfbreds with Beetal and Jamunapari at six months of age but had a non-significant effect on other measurements like body length and height at withers. Heart girth of monsoon born kids was significantly more than those of winter and summer seasons.

2.3 MILK PRODUCTION

The least-squares mean of lactation yield for nondescript and graded Sirohi goats was reported to be 114.22±22 kg in a lactation period of 167.28±0.82 days (Gokhale *et al.*, 1997).

Patel *et al.* (1999) reported that peak yield in a day of Marwari and Parbatsar goats in hot arid rangelands were 1.04±0.06 and 1.53±0.13 kg respectively.

Saikia *et al.* (2000) reported that the average milk yield of Assam local and crossbred was 434.75±54.27 and 809.06±64.23 ml/ day respectively.

Singh *et al.* (2000b) reported that weekly peak yield of Black Bengal and its halfbreds was 4.40±0.08 kg.

Kumar *et al.* (2004) reported that the peak yield of Kutchi goats under semi arid condition of Rajasthan was 1.16±0.11 kg per day.

The average peak yield of Malabari goats was found to be 850.80±62.91 ml under field conditions (Anon., 2007).

Mohammed *et al.* (2007) reported an average lactation peak of 1.4± 0.20 kg after 4 weeks in the Sudanese Nubian goats under farm conditions.

2.3.1 Factors Affecting Milk production in Malabari Goats

Variation within breed in milk production was reported in different breeds. In Malabari goats, the effect of centre, season and year of kidding were significant sources of variation affecting peak yield (Anon., 2007).

2.3.1.1 Effect of Centre

Gokhale *et al.* (1997) reported that the effect of location on milk yield was significant in nondescript and graded Sirohi goats. The goats maintained in Mandal block area produced significantly lower milk yield compared to those in Asind area. The village wise variation in milk yield was significant.

Crepaldi *et al.* (1999) reported that milk yield is primarily influenced by herd-year factor in Alpine goats in Lombardy in Italy.

2.3.1.2 Effect of Year of Kidding

Mavrogenis (1984b) reported that year of kidding had significant influence on milk production and lactation length in Damascus goats.

Gokhale *et al.* (1997) reported that the effect of year of kidding was significant on milk yield for rural goats in Rajasthan. The does kidded during 1995-96 yielded more milk than those kidded during 1991-92 and 1993-94.

Kumar *et al.* (2004) reported that year of kidding had a highly significant effect on peak yield of Kutchi goats under semi arid condition of Rajasthan.

2.3.1.3 Effect of Season of Kidding

According to Mavrogenis (1984b), month of kidding had significant influence on milk production in Damascus goats.

Gokhale *et al.* (1997) reported that effect of month of kidding on milk yield was significant on rural goats in Rajasthan. Goats kidded between August and October produced more milk yield as compared to those kidded during January to July and November to December.

Crepaldi *et al.* (1999) reported that season of kidding significantly influenced milk yield. Goats kidding early in the year had higher milk yields, whereas goats that kidded in summer had the lowest yields in Alpine goats in Lombardy in Italy.

According to Singh *et al.* (2000b), the season of kidding had no significant influence on lactation yield and weekly peak yield in Black Bengal and its halfbreds.

Kumar *et al.* (2004) observed a non-significant effect of season of kidding on peak yield of Kutchi goats under semi arid condition of Rajasthan whereas a significant effect was noted in case of 90 and 150 days milk yield and total milk yield.

Mohammed *et al.* (2007) reported that season of birth had a significant effect on total milk yield of the Sudanese Nubian goats under farm conditions and those kidded in dry summer produced more milk than any other season.

2.4 PROLIFICACY

Shanmughasundaram (1957) recorded 58.5 percentage twinning and 41.5 percentage single births out of 103 kiddings in Malabari goats.

Mathew (1991) recorded a higher percentage of singles (68%) in Malabari goats followed by twins (29.5%) and triplets (2.5%).

Patel *et al.* (1999) recorded the percentage of singles and twins in Marwari and Parbatsar breeds in hot arid rangelands as 81.3 and 18.7, and 95.8 and 4.2 respectively.

Raghavan *et al. (*2004) reported that under field conditions the percentage of singles, twins, triplets and quadruplets were 32.15, 53.54, 12.86 and 1.45 respectively in Malabari goats.

Mathew *et al.* (2005) reported that the overall average of litter sizes from first parity to sixth parity was 1.3 ± 0.02 in Attapadi Black goats. The incidence of singles was greater (73%) and the rate of twinning was 26.1%. The incidence of triplets (0.8%) and quadruplets (0.1%) were low.

Bindu (2006) observed a higher percentage of twin births in Malabari goat populations, which was 58.95, 54.46 and 53.37 respectively in Tanur, Thalassery and Badagara regions of Northern Kerala.

Seena (2006) reported that the percentage of births of singles, twins, triplets and quadruplets were 38.33, 51.67, 9.17 and 0.83 respectively in Malabari goats.

The percentage incidence of birth for singles, twins, triplets and quadruplets in Malabari goat were reported to be 33.4, 59.0, 7.3 and 0.3% respectively under field conditions. Tanur area had higher percentage of multiple births (70%) compared to Tellichery (67%) and Badagara (63%) areas (Anon., 2007).

2.5 HERITABILITY OF BODY WEIGHT AND BODY MEASUREMENTS

Heritability is an important genetic parameter which gives an indication of the genetic causes of variation in the trait and construction of selection index is done by taking into consideration the heritability of the trait in question also (Hazel, 1943).

2.5.1 Heritability of Body Weights

Iloeje and Van Vleck (1978) reported that the heritability of body weights at one, two, three, five and seven months were 0.63, 0.51, 0.48, 0.49 and 0.49 respectively for young Saanen goats.

Madeli and Patro (1984) estimated the heritability of body weights at different ages in Ganjam goats. The heritability of birth weight was lowest (0.185±0.139) whereas that of 18 month was highest (0.652±0.412). The estimates at other ages (6, 12 and 24 months) ranged between 0.320±0.318 and 0.357±0.257.

Malik *et al.* (1986) reported the heritability of birth weight as 0.23 and 0.21 for Beetal and Black Bengal kids respectively. For Beetal kids the heritability estimates of weight at subsequent ages up to weaning were near to zero whereas for Black Bengal kids these estimates were 0.26, 0.43 and 0.20 for live weights at 30, 60 and 90 days of age respectively.

Saxena *et al.* (1990) estimated the heritability of birth weight, weaning weight, pre-weaning gain and average pre-weaning daily gain in Jamunapari goats. The heritability estimate for birth weight was non-significant while that of weaning weight was moderate (0.474±0.216). The heritability estimates of pre-weaning gain (0.0151±0.202) and average daily pre-weaning gain (0.155±0.214) were low.

Menon (1994) estimated the heritability of body weights at different ages in Malabari and Alpine×Malabari. The heritabilities of the Malabari breed in respect to body weight were 0.63±0.07 at birth, 0.46±0.08 at three months, 0.22±0.06 at six months, 0.72±0.05 at nine months and 0.60±0.07 at 12 months. In the Alpine

×Malabari crossbreds the heritabilities in the above order were 0.06±0.06, 0.19 ±0.07, 0.22±0.08, 0.03±0.07 and 0.14±0.09.

Heritability estimates of body weights at birth, weaning, 24 weeks, 48 weeks and 72 weeks as well as average daily gains were calculated and found to be moderate to low for live weights, and average daily gain, which ranged from 0.099±0.039 for live weight at weaning to 0.153±0.053 for average daily gain from birth to 24 weeks of age in Blended goats at Malya in Tanzania (Das *et al.*, 1996).

Roy *et al.* (1997) estimated the heritability for body weights at three, six, nine and twelve months for Jamunapari goats and the values were 0.30±0.10, 0.51±0.12, 0.23±0.19 and 0.31±0.10 respectively.

Schoeman *et al.* (1997) compared the heritability of body weights of birth and weaning in Boer goats between two herds. The heritability estimates were 0.327 and 0.273 in one herd and 0.357 and 0.602 in another herd. They also estimated the heritability of six month, nine month and yearling weight in second herd as 0.597, 0.400 and 0.355 respectively.

Mourad and Anous (1998) reported that the heritability estimates for body weight from birth up to sixty days of age ranged from 0.54 to 0.68; and they had moderate values for 90 to 210 days of age, ranging from 0.39 to 0.49 indicating high genetic variability.

Singh and Singh (1999b) reported the heritability estimates for body weights at different ages and gain in body weight were low to moderate in magnitude in Beetal × Black Bengal kids.

According to Singh *et al.* (2000a), the heritability estimate of birth weight of Beetal halfbred kids was 0.71±0.04. The heritability estimate of three and six months body weights were 0.22±0.02 and >1 respectively.

Nahardeka *et al.* (2001) estimated the heritability of body weights of six, nine and twelve months of age of Assam local goats and their crosses with Beetal as 0.26±0.12, 0.16±0.11 and 0.31 ±0.21 respectively.

Al-Shorepy *et al.* (2002) reported that the estimates of direct heritability for early growth traits in Emirati goat were 0.18 for birth weight, 0.16 for weight at 30 days, and 0.32 for weaning weight. The heritability estimates for the average daily gains for the periods from birth to thirty days, thirty to ninety days and birth to weaning were 0.11, 0.09 and 0.42 respectively.

Portolano *et al.* (2002) reported that the heritability estimates decreased with the increase in body weights of the Sicilian Girgentana kids. Heritability estimates of the body weights were rather low, but consistently higher than those of average daily gain trait. The highest heritability estimate was for birth weight (0.49±0.07).

Rai *et al.* (2004) reported that the heritability estimate of birth weight of Marwari goats was 0.230±0.112 whereas the heritability estimate of three and six month body weights were 0.183±0.103 and 0.251±0.116 respectively.

Kosum *et al.* (2004) estimated the heritability of birth and weaning weights in Saanen, Bornova and Saanen×Kilis goats using REML analysis. Heritability estimate for birth and weaning weights were 0.43 and 0.05 respectively.

According to Bosso *et al.* (2007), estimates of heritability for birth weight, weaning weight, yearling weight, and pre-weaning as well as post-weaning growth rate were 0.5, 0.43, 0.30, 0.32 and 0.11 for West African Dwarf goats and 0.39, 0.54, 0.21, 0.54 and 0.23 for Djallonk´e sheep respectively.

Sharma and Pathodiya (2007) reported that the heritability estimates of body weight at birth, three and six months of age of Sirohi kids under farmers' management system were 0.530±0.151, 0.061±0.072 and 0.284±0.112 respectively.

Mugambi *et al.* (2007) estimated the heritability of birth, weaning and yearling weight and pre-weaning and post-weaning average daily gain of Kenya Dual Purpose Goats. The heritability estimates were low ranging from 0.10±0.02 for post- weaning daily gain to 0.24±0.01 for pre-weaning average daily gain.

Otuma and Osakwe (2008) reported that heritability estimates of live weight traits were moderate to high in Nigerian Sahelian goats. Various heritability estimates for birth, three months, twelve months and eighteen months body weights were 0.41±0.08, 0.45±0.31, 0.45±0.28 and 0.42±0.99 respectively.

The mean values and standard errors (SE) of direct additive heritability estimates calculated were 0.17±0.07, 0.22±0.08, 0.07±0.07, 0.10± 0.08, 0.30±0.12 and 0.08±0.10 for birth weight, 90 day weight, average daily gain up to 90 days, 300 days weight, average daily gain from birth to 300 days and average daily gain from 90 to 300 days, respectively in Boer goats (Zhang *et al.,* 2009).

2.5.2 Heritability of Body Measurements

Khadanga *et al.* (1987) estimated the heritability of height at withers, heart girth and oblique body length at one year of age in Ganjam goats. The values were 0.246±0.236, 0.313±0.303 and 0.437±0.328 respectively.

Manfredi *et al.* (2001) estimated the genetic parameters of type appraisal in Saanen and Alpine goats and animal size, measured as the thorax perimeter, had high heritability (0.41 for Saanen and 0.50 for Alpine).

According to Karna *et al.* (2001) the heritability estimates for body length, height at withers and chest girth at birth were 0.435±0.149, 0.018±0.041 and 0.058±0.052 respectively for Chegu goats.

Singh (2002) reported that the heritability estimate of body measurements in Black Bengal and its halfbreds with Beetal and Jamunapari kids at six months of age was moderate to high in magnitude and the values ranged from 0.20±0.09 to 0.47±0.10.

Janssens and Vandepitte (2004) reported that the heritability estimates of height at withers, body length and heart girth were 0.43, 0.30 and 0.45 respectively in Bleu du Maine sheep. They also estimated the heritability estimate of these traits in Suffolk and Texel sheep and the values were 0.57, 0.35 and 0.39 and 0.40, 0.28 and 0.40 respectively.

Zhang *et al.* (2008) analyzed the variance components and genetic parameters for size at birth in the Boer goat and the heritability estimates for body length, height and chest girth were 0.14±0.07, 0.24±0.09 and 0.25±0.10 respectively.

2.6 CORRELATIONS AMONG BODY WEIGHTS AND BODY MEASUREMENTS

Knowledge about the genetic and phenotypic correlations between body weights and body measurements is necessary for the construction of an index for selection of goats (Hazel, 1943).

2.6.1 Genetic Correlation

2.6.1.1 Genetic Correlation among Body Weights

Madeli and Patro (1984) reported that the genetic correlation between body weights at birth and six month was positive and very high whereas the genetic correlations between birth weight and weight at 12, 18 and 24 months of age were negative in Ganjam goats.

Roy *et al.* (1997) reported that the genetic correlations among body weights at three, six, nine and twelve months of age for Jamunapari goats were positive and ranged from 0.00±0.228 (between three and six months) to 0.91±0.05 (between nine and twelve months of age).

Singh and Singh (1999b) observed that the genetic correlation of weight at six, nine and twelve months of age with earlier weights at 4 weeks, eight weeks and three months as 0.87±0.07, 0.78±0.12 and 0.70±0.17; 0.87±0.07, 0.78±0.12 and 0.68±0.18 and 0.84±0.09, 0.98±0.01 and 0.86±0.09 respectively. The positive and high magnitude of genetic correlations indicated that kids could be selected on the basis of pre-weaning weights for improvement in body weight during post-weaning period.

Nahardeka *et al.* (2001) found that the genetic correlations of body weights at six, nine with twelve months of age of Assam local goats and their crosses with Beetal were medium to high and positive.

Portolano *et al.* (2002) observed that the genetic correlations between all body weights in Sicilian Girgentana kids within two months of age ranged from 0.77 to 0.98 and significantly differed from zero. Body weights at birth were highly correlated genetically with all the other traits studied (ranging from 0.91 with body weight at 15 days to 0.86 with body weight at 60 days).

Al-Shorepy *et al.* (2002) reported genetic and phenotypic correlations between early growth traits in Emirati goat like weight at birth, 30 days and at weaning, and average daily gains between these periods were positive and of medium to high magnitude for the majority of traits except between birth weight and average daily gain for the period from birth to thirty days. Genetic correlations between traits were larger than the majority of corresponding phenotypic correlations. The largest relationships were found between chronologically adjacent traits.

The genetic correlations were moderate between birth weight and subsequent body weights at 90 days, 120 days and 360 days in the case of West African Dwarf goats and Djallonk´e sheep. The genetic correlations were high between post- weaning growth rate and body weights at 120 days, 360 days and birth weight (0.92,0.83 and 0.70 respectively) in goats, whereas the genetic correlation between pre weaning growth rate and birth weight was low (0.26) in sheep (Bosso *et al.*, 2007).

Mugambi *et al.* (2007) reported that the genetic correlations between birth weight and weaning weight, and birth weight and pre-weaning average daily gain were positive and low (0.15±0.04 and 0.001±0.2) while the genetic correlation between weaning weight and pre-weaning daily gain was high and positive (0.9±0.006).

Sharma and Pathodiya (2007) reported that the genetic correlation between birth weight and three months body weight was 0.037±0.458 and body weight at three and six months was 0.288±0.454 in Sirohi kids under farmers' management system. The genetic correlation between body weight at birth and at six months was negative.

Otuma and Osakwe (2008) reported positive genetic correlations among the weight traits at birth, three months, twelve months and eighteen months of age in Nigerian Sahelian kids.

2.6.1.2 Genetic Correlation among Body Measurements

Janssens and Vandepitte (2004) reported positive genetic correlation between height at withers, body length and heart girth in Belgian Bleu du Maine, Suffolk and Texel sheep. The genetic correlations with height at withers to body length and heart girth in three breeds were 0.88 and 0.51, 0.72 and 0.68, and 0.46 and 0.39 respectively. The correlation coefficients with length and heart girth in these breeds were 0.72, 0.78 and 0.52 respectively.

Zhang *et al.* (2008) reported high and positive genetic correlations between the birth traits in Boer goats; the lowest was 0.75±0.160 (body length-height), and the highest was 0.94± 0.083 (height- chest girth).

2.6.1.3 Genetic Correlation between Body Weights and Body Measurements

Menon (1994) estimated the genotypic correlations of body length, girth and height with body weights in Malabari and its crosses at birth, 3, 6, 9 and 12 months of age. It was found that heart girth showed better genetic correlation with body weights at all ages compared to body length and height.

Karna *et al.* (2001) reported that the genetic correlation between birth weight and corresponding body length, height at withers and chest girth were more than 1.0, 0.93±0.60 and 0 respectively in Chegu goats.

Singh (2002) reported that genetic correlations of body weight with different body measurements like body length, height at withers, heart girth and paunch girth were positive and moderate to high in magnitude except between weight and paunch girth which exceeded the theoretical limit.

2.6.2 Phenotypic Correlation

2.6.2.1 Phenotypic Correlation among Body Weights

Mavrogenis (1984a) reported that the phenotypic correlation of birth weight with weaning weight and weight at 140 days was 0.43 and 0.37 respectively whereas the same between weaning weight and weight at 140 days were 0.71 in Damascus goats.

Malik *et al.* (1986) reported that the pre-weaning growth traits like body weights at birth, 30, 60 and 90 days of age were positively and significantly correlated among themselves at phenotypic level in Beetal and Black Bengal kids.

According to Singh *et al.* (2000a), the phenotypic correlation of body weight at birth to body weight at three and six months of age for Beetal halfbred kids were 0.06±0.04 and 0.46±0.04 respectively. The phenotypic correlation between body weight at three and six months of age was 0.37±0.04.

According to Roy *et al.* (2003), the phenotypic correlation of body weights at birth to three and six months in Jamunapari kids were 0.29 and 0.24 respectively. The phenotypic correlation between body weights at three and six months of age was 0.72.

Rai *et al.* (2004) reported that the phenotypic correlation between body weights at birth, three and six months of age were positive and significant in Marwari goats, ranging from 0.485 (birth weight and six months weight) to 0.841 (weight at three and six months).

Sharma and Pathodiya (2007) reported that the phenotypic correlation between body weight at birth and three months of age was 0.114±0.033. The phenotypic correlation between body weights at three and six months of age was 0.651±0.029. But the correlation between body weights at birth and six months of age was negative.

2.6.2.2 Phenotypic Correlation among Body Measurements

Deb *et al.* (1998) reported that the correlation between conformation traits like heart girth with height and length was significantly high (r=0.95) in Pashmina goats.

Janssens and Vandepitte (2004) reported positive phenotypic correlation between height at withers, body length and heart girth in Belgian Bleu du Maine, Suffolk and Texel sheep. The correlation coefficients of heart girth with height at withers and body length were 0.34 and 0.32 in Belgian Bleu du Maine, 0.34 and 0.36 in Suffolk, and 0.32 and 0.31 in Texel sheep respectively. The phenotypic correlation coefficients between length and height at withers in these breeds ranged from 0.31 to 0.40.

2.6.2.3 Phenotypic Correlation between Body Weights and Body Measurements

Mukherjee *et al.* (1981) estimated the phenotypic correlations of body weight with length, height at withers and chest circumference in Gray Bengal females aged 0-3, 3-6, 6-12, 12-36 and above 36 and found that all correlations were significant, with the highest being with chest circumference (0.74±0.09 to 0.95±0.04).

According to Prasad *et al.* (1981), the largest correlations among body measurements to body weights were those involving chest circumferences. This was revealed in a study involving body weight, length, withers height and chest circumference in female Black Bengal goats, aged 0-3, 3-6, 6-12 12-36 and above 36 months.

Mukherjee *et al.* (1983) studied the body weight-measurement relationship of Grey Bengal goats under the three agro-climatic conditions. Except in three to six months age group, the correlation of body weight with chest girth was significant in all the cases. Following chest girth, the association of body weight with length was significant, while the correlation of body weight with height was significant in the least number of cases.

Mukherjee *et al.* (1986) compared the correlation of body weight with length, height and chest girth in Brown Bengal does in three agro-climatic zones. In birth to three months age group, body length showed highest correlation with body weight in all three zones, followed by chest girth in plain and plateau, and height in sub plateau region. In three to six months age group, height showed highest correlation in plain and sub plateau, whereas it was length in plateau region.

Menon (1994) estimated the phenotypic correlations of body length, girth and height with body weights in Malabari and its crosses at birth, 3, 6, 9 and 12 months of age and the values were very high in all ages studied. The correlation coefficients ranged from 0.658 ± 0.079 to 0.944 ± 0.048.

Badi *et al.* (2002) compared the correlation between physical characteristics such as live weight, heart girth and height at withers in two types of Eritrean goats such as Barka and Afar. They noticed a high correlation between heart girth with live weight for Barka and Afar to as high values as 0.95 and 0.94 respectively, and for the same types the correlation of height at withers with live weight was 0.92 and 0.89 respectively, and with regard to the sex, with in groups the correlation of heart girth with live body weight was 0.95 for male and 0.91 for female groups. The correlation of height at withers with live body weight was 0.92 for male and 0.85 for female groups.

Thiruvenkadan (2005) observed positive and highly significant correlations between body weight and body measurements in Kanni Adu kids. Among the three body measurements, chest girth had the highest correlation coefficient in males at 0-3 months and in females of 3-6 months, and in both sexes at 0-12 month age groups. The body length had the highest correlation coefficient in males of 3-6 months and in females of 6-9 and 9-12 months of age. The height at withers had high correlation with body weight in males of more than 6-9 and 9-12 months and in females of 0-3 months age groups.

Adeyinka and Mohammed (2006) reported that chest girth showed highest correlation with body weight for the two sexes (0.99 for females and 0.73 for males) in Nigerian Red Sokoto goats followed by body length and height at withers.

2.7 GENETIC PARAMETERS OF MILK PRODUCTION

For construction of selection indices involving milk yield of dam, genetic parameters of milk yield are necessary. Peak yield gives an indication of the total lactation yield of the animals (Singh and Kumar, 2007).

2.7.1 Heritability

According to Kennedy *et al.* (1982), heritabilities of milk production for Alpines, Saanens, and Toggenburgs were high and ranged from 0.61 to 0 .69.

Mavrogenis (1984b) reported that the heritability estimates of 90 and 150 day milk production were identical in Damascus goats and it was 0.29±0.14.

Kumar *et al.* (2004) reported that the heritability estimate of peak yield in Kutchi goats in semi arid condition of Rajasthan was 0.36±0.17.

According to Rai *et al.* (2001a) the heritability estimate of 90 and 150 day milk yield, total lactation milk yield and average daily milk yield were 0.482±0.188, 0.481±0.187, 0.519±0.195 and 0.359±0.163 respectively in Marwari goats.

According to Morris *et al.* (2006) the heritability estimate of daily milk yield in Saanen goat herd in New Zealand was 0.35±0.03.

2.7.2 Correlation of Milk Production with Body Weights and Body Measurements

Ehoche and Buvanendran (1983) reported that in case of Red Sokoto goats, correlation between milk yield and weight gain of kids remained at about 0.50 throughout pre-weaning period for singles, but increased from 0.09 at the beginning of lactation to 0.57 at the end of pre-weaning period for twins.

According to Misra *et al.* (1985), pre-weaning body weights of Sirohi kids were significantly affected by dam's milk yield.

According to Guessous *et al.* (1989), lamb birth weight had very little influence on dam milk production. In fact, the correlation coefficient between these two parameters was at its maximum during the first week (r = 0.28). It then decreased rapidly to reach 0.03 only at the end of the 4th week of lactation. On the other hand, there was a high correlation between lamb weight at 35 days of age and ewe milk production during the first 5 weeks of lactation (r = 0.90).

Sangre and Pandey (2000) reported that kid growth during the first three months of life is largely determined by the milk production of their dams. The growth rate of kids was influenced significantly by the milk production of their dams.

Jithendrakumar (2003) reported that correlation between dam's milk yield and pre-weaning body weights of kids of Malabari goats was positive and ranged from 0.338 to 0.458.

2.8 PREDICTION OF BODY WEIGHT FROM BODY MEASUREMENTS

Knowledge about the correlation between body weight and body measurements and measures to predict body weight from body measurements is essential to get an idea about the weight gain in goats under field conditions.

Bhattacharya *et al.* (1984) fitted simple and multiple linear regression models for the estimation of body weight of Black Bengal goats. For this, the measurements used were heart girth, height at withers, length and circumference of neck at the base. Prediction equations based on heart girth and length, and heart girth and neck area were found to be equally effective with a coefficient of multiple correlation (R^2) of approximately 0.91.

Das *et al.* (1990) developed prediction equations for body weights based on length, height, heart girth and hip measurement for Jamunapari and Barbari kids at birth, three months and six months of age. Heart girth alone could be used effectively for prediction of body weight of kids at three and six months. The combination of heart girth and height was a better predictor for body weight at three and six months in kids of both the breeds than any other combinations.

Menon (1994) compared two multiple regression models with body length, heart girth and height at withers as well as chest girth and square of chest girth as dependent variables from birth to one year of age at three months interval in Malabari and its crosses in Kerala. The highest R^2 were observed at six months of age in both models. In all the age groups higher R^2 was observed in the prediction equations with all the measurements as compared to chest girth alone.

Mayaka *et al.* (1995) estimated the live body weight in West African dwarf goats from heart girth measurement. It was found that this accounted for 56 to 95% of total variation in weight. Allometric curvature in the case of pooled data within sex yielded a best fit with adjusted R^2 above 0.96 when compared to a linear one.

Sharma and Das (1995) developed various equations for predicting body weight from various body measurements in Jamunapari goats at different ages. At birth, all three linear body measurements were poor predictors of body weight as the coefficient of determination was only 65%. Combination of withers height and heart girth could be used to estimate the body weight at weaning age and post-weaning period.

Mohammed and Amin (1996) developed various prediction equations for estimation of body weight for singles, twins and triplets from morphometric measurements of Sahel goats. For singles and twins there was a good correlation (r^2= 0.98) with body weight and heart girth. So weight could be estimated indirectly from heart girth alone. But for triplets, height at withers also showed highest correlation along with heart girth (r^2= 0.98). So weight could be predicted using heart girth alone or heart girth and height at withers together.

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Benyi (1997) estimated the live weight from chest girth in pure and cross bred West African goats. The coefficient of determination ranged from 0.87 to 0.92 and 0.97 to 0.99 for linear and geometric equations respectively. The geometric equations estimated live weight with a higher degree of reliability regardless of girth size than linear equations.

Slippers *et al.* (2000) developed linear regression relationship between heart girth and body weight in Nguni goats. Separate prediction equations were developed for bucks and does which had higher R^2 values of 88.1% and 94.3% respectively. From this study, they concluded that the body weight of Nguni goats could be predicted with confidence from heart girth measurement.

Badi *et al.* (2002) suggested that regression equations could be used for prediction of live weight from height at withers and heart girth in Eritrean goats and the best estimate of live body weight was that from heart girth (adjusted R^2 of 0.89) and the height at withers could be used as a supplementary variable for additional information.

Thiruvenkadan (2005) fitted simple and multiple regression models with body weight as dependent variable and height at withers, chest girth and body length as independent variables in Kanni Adu. The chest girth accounted maximum of 80.4 to 93.6% of total variation in body weight. He suggested that weight could be estimated more accurately with a combination of two or more measurements.

Adeyinka and Mohammed (2006) checked the accuracy of body weight prediction in Nigerian Red Sokoto goats raised in North Eastern Nigeria using linear body measurements. In the males the best predictive variables were chest girth, height at withers and body length (R^2 =56%), while for females only chest girth and body length (R^2 =92%) were enough to predict live weight even more accurately.

Joseph (2007) developed prediction equations for estimation of body weight of adult female Malabari goats based on the power function of chest girth.

2.9 SELECTION INDICES

2.9.1 An Introduction to Selection Index

Smith (1936) constructed an index for selecting varieties of wheat. He expressed the value of a plant as a linear function of its characters. Then using the concept of a "discriminant function", a linear function of the observable characters was derived which was the best available guide to the genetic value of each line.

Hazel and Lush (1942) compared the efficiency of index selection with that of the other two methods, tandem selection and independent culling method. They showed that the genetic gain computed was highest in index selection, followed by independent culling and tandem selection.

Hazel (1943) extended the technique of selection index to animals for selection between individuals in an interbreeding pig population. He developed a method of computation of linear selection index.

Panse (1946) compared straight selection with selection index constructed on the basis of "discriminant function" in poultry. The traits included in his study were number of eggs laid during a period of five months, average egg weight, the body weight of pullet and age at sexual maturity. Based on this study, he concluded that selection with the help of this function produced higher genetic advance than straight selection.

Karam *et al.* (1953) applied the modification of Hazel's method by Henderson in selecting lambs and the modification separated application of selection index into two steps. The first step was estimation of individual breeding values for each trait included in the definition of aggregate breeding value. The second step was application of relative economic values.

Hanson and Johnson (1957) developed methods for calculating and evaluating a general selection index obtained by pooling information from two or more experiments.

Tallis (1962) extended the method of restricted selection index of Kempthorne and Nordskog (1959) to the case of selection for an optimum genotype.

Yamada *et al.* (1975) suggested a method of selection index where relative economic values of individual traits were unknown or otherwise difficult to assess, provided that the breeder had a definite breeding objective for improving individual traits of his concern.

Cunningham (1975) extended selection index theory to cover the case of selection in several stages. He used general algebra for adjusting in later stages the effects of selection in early stages.

Hazel *et al.* (1994) explained the various developments in selection index theory and present and future uses of index selection in livestock improvement.

2.9.2 Selection Indices in Goats

Selection index has an advantage over other methods of selection in that it takes into consideration more number of traits which are of economic importance. Different types of indices are constructed based on the availability of information and purposes for which the index is made.

2.9.2.1 General Selection Indices

Rema (1985) developed different selection indices for crossbred dairy goats using four characters: birth weight, age at first kidding, body weight at first kidding, and first lactation milk yield, under farm conditions. Index was calculated on the relative economic value of birth weight, age at first kidding, body weight at first kidding and first lactation milk yield by taking into consideration the cost of production of each trait.

Khadanga *et al.* (1987) constructed selection indices in Ganjam goats for improvement of meat production incorporating body weight, height at withers, heart girth, and oblique body length at one year of age. Four selection indices were constructed using different combinations of the four traits. They concluded that improvement in body weight due to selection for that trait alone was 35% less than the response due to index selection.

Singh *et al.* (1991) checked the relative effectiveness of different selection indices for genetic advancement in Black Bengal goats by incorporating growth traits. They calculated the relative economic values for birth weight, body length, height at withers and heart girth at three months age on the basis of simple regression of body weight at six months of age on these traits for Black Bengal goats. The relative economic value of three month body weight was calculated as the ratio of cost value per unit body weight of kids at three months of age and cost per unit of body weight at six months. Index constructed by incorporating traits like birth weight, body weight, length, height at withers, heart girth at three months of age and body weight at six months of age was expected to achieve more genetic gain in body weight at birth, three and six months of age.

Singh and Singh (1998) studied the effectiveness of different selection indices for genetic advancement in carcass yield of Black Bengal goats. They constructed various selection indices incorporating five pre-slaughter traits including body weight and body measurements and hot carcass yield.

Singh and Singh (1999a) compared the various selection indices for genetic advancement in carcass yield of Jamunapari×Black Bengal goats.

Mourad and Anous (2000) compared the efficiency of selection index with mass selection for improved growth performance of goats. They concluded that mass selection either on marketing body weight or on average daily gain from birth to one month of age was less effective than the selection index.

Rai *et al.* (2001b) developed four selection indices by incorporating growth traits (body weight at three, six and nine months of age, 0-3, 3-6, 6-9 months weight gain) in different combinations in Marwari goats. They derived relative economic values for various growth traits (body weight at three, six and nine months of age and 0-3, 3-6, 6-9 month weight gain) from the market and farm price analysis by defining the economic worth of a trait as the amount of profit in rupees because of the change in the trait by one metric unit in Marwari goat. Index combining body weight at three and nine months of age and 3-9 months weight gain was found to be most appropriate with relative efficiency of 160% and an expected genetic gain of 0.921.

Rai *et al.* (2001c) developed four weight free selection indices incorporating growth traits (body weight at three, six and nine months of age) and 3-9 month weight gain in different combinations in Marwari goats. Indices involving body weight at six and nine months of age and index with body weight at three and nine months of age and 3-9 month weight gain had higher efficiencies.

Yadav *et al.* (2005) constructed two types of selection indices for growth traits in closed flocks of Kutchi goats. They determined the relative economic values for growth traits (three and nine month body weight, 3-6, 3-9 and 3-12 month weight gain) of Kutchi goat on the basis of cost incurred on feeds given to the goats, labour, supervisory and miscellaneous charges, and the average market rates at which the products were sold. They found that weight free indices were found more efficient in comparison to weighted indices for ranking the sires.

2.9.2.2 Restricted selection indices

Under certain conditions, the breeder may like to effect change in the means of certain traits (r) out of p traits while keeping the means of p-r traits unchanged. This was done for restricted selection by Kempthorne and Nordskog (1959) with the constraints that some linear functions of genotypic values would remain constant.

Rema (1985) constructed restricted selection indices for the Malabari and its crossbreds with Alpine and Saanen by imposing restriction on either birth weight or age at first kidding or body weight at kidding or combinations of any two.

Alkass *et al.* (2002) constructed restricted selection indices for milk yield and growth of local kids crossed with Damascus and Saanen breeds in Iraq. Restricted selection indices for total milk yield with restriction on body weight at sixth months and for weight at six and twelve months with restriction on body weight at 18 months were constructed.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 POPULATION

Malabari goat which is one of the most prolific milch breeds of India is found mainly in the northern districts of Kerala. Genetic improvement of this breed is the main objective of All India Co-ordinated Research Project (AICRP) on goats. Selection based on body weight, dam’s yield and prolificacy is considered to be the best option for improvement of this breed. So, for the formulation of an index for selection, the data pertaining to three field centres were collected. The centres were Tellichery in Kannur district (Centre 1), Badagara in Kozhikode district (Centre 2) and Tanur in Malappuram district (Centre 3).

3.2 DATA COLLECTION

Data on animals born during the period from August 2005 to August 2008 were utilized for the study. A total of 1055 records were used. Data on the following traits were collected.

3.2.1 Traits of Economic Importance

Body weight (in kg) at three stages, *viz.*,

a) Below one month
b) Three months and
c) Six months of age

Body measurements *viz.*, chest girth, body length and height at withers (cm) at the above ages

Chest girth was measured by taking the measurement of the circumference of the chest using a measuring tape.

Paunch girth was measured as circumference at the navel and it was used only for the prediction of body weight.

Body length was measured as the distance from point of shoulder to pin bone.

Height at withers was measured as the distance from the surface of the platform to the withers.

Peak yield of dam

Recorded in milliliters as the highest yield in a lactation period.

3.2.2 Factors Causing Variations in the Economic Traits

Centre (area); sex of the kid; type of birth as singles, twins, triplets and quadruplets; sire of the kid, dam of the kid, season of birth and year of birth were recorded.

To study the effect of season on different economic traits, the whole year was divided into three main seasons *viz.*, 1.January to April (summer) 2. May to August (rainy) and September to December (winter)

3.3 STATISTICAL ANALYSES

3.3.1 Effect of Non-genetic Factors on Body Weight and Body Measurements

To find out the effect of non-genetic factors on body weight and body measurements, the data on body weight, chest girth, body length and height at withers at below one, three and six months of age were subjected to least-squares analysis (Harvey, 1960). They were adjusted for non-genetic factors *viz.*, centre, sex, type of birth, year and season of birth before proceeding with genetic analysis.

The model used was

$$Y_{ijklmn} = \mu + S_i + E_j + Z_k + A_l + M_m + e_{ijklmn}$$

where, Y_{ijklmn}- Observation of n^{th} kid of the i^{th} centre, j^{th} sex, k^{th} type of birth, l^{th} year of birth, m^{th} season of birth

μ- Overall mean

S_i- Effect of i^{th} center (i = 1,2,3)

E_j – Effect of j^{th} sex (j = 1,2)

Z_k - Effect of k^{th} type of birth (k = 1,2,3,4)

A_l - Effect of l^{th} year of birth (l = 1,2,3,4)

M_m – Effect of m^{th} season of birth (m = 1,2,3)

e_{ijklmn} – Random error

Duncan's multiple range test as modified by Kramer (1957) was used to compare means.

3.3.2 Effect of Non-genetic Factors on Peak Yield of Dam

Peak yield was subjected to least-squares analysis (Harvey, 1960) to study the effect of non-genetic factors *viz.*, centre, year of kidding and season of kidding. The data was then adjusted for non-genetic effects to estimate genetic parameters.

The model used was

$$Y_{ijkl} = \mu + S_i + E_j + Z_k + e_{ijkl}$$

where, Y_{ijkl}- Observation of n^{th} kid of the i^{th} centre, j^{th} year of kidding, k^{th} season of kidding.

μ- Overall mean

S_i- Effect of i^{th} centre (i = 1,2,3)

E_j – Effect of j^{th} year of kidding (j = 1,2,3,4)

Z_k - Effect of k^{th} season of kidding (k = 1,2,3)

e_{ijkl} – Random error

The random errors were assumed to be normally and independently distributed with mean $[E(e_i)]$ zero and variance σ^2_{ei}.

Duncan's multiple range test as modified by Kramer (1957) was used to compare means.

3.3.3 Estimation of Heritability

The calculations of heritability for body weight and body measurements at below one, three and six months of age and peak yield of dam were done by the SPAB 2.0- Software Statistical package for animal breeding (Sethi, 2002). The data adjusted for the effect of non-genetic factors were used for the estimation of heritability. The minimum numbers of progeny to qualify for inclusion was assumed to be five per sire. Heritability was estimated by paternal half sib correlation method (Becker, 1975). The model used was

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

Where, Y_{ij} - Observation of j^{th} progeny of i^{th} sire

μ - population mean

S_i – Effect due to i^{th} sire with $E(S_i)= 0$ and $V(S_i)= \sigma^2_{si}$ (i = 1,2,3….n)

e_{ij} – Random effect due to error with $E(e_i)= 0$ and $V(e_i)= \sigma^2_{ei}$

The analysis of variance (ANOVA) was

Source of variation	d.f.	Sum of squares	Mean sum of squares	Expected sum of squares
Between sires	s-1	BSS	MSs	$\sigma^2 e + k\sigma^2 s$
Within sires between progenies	n-s	WSS	MSe	$\sigma^2 e$

Where,

$$k = \frac{1}{s-1}\left(n - \frac{\sum n_i^{\,2}}{n}\right)$$

s = total number of sires

n = total number of progenies of all sires

n_i = total number of progenies of i^{th} sire

The heritability was then calculated as

$$h^2 = \frac{4\sigma^2 s}{\sigma^2 s + \sigma^2 e}$$

where,

$\sigma^2 s$ = sire variance

$$= \frac{MSs - MSe}{K}$$

$\sigma^{2}e$= Error variance or mean sum of squares due to error

The standard error of heritability was calculated by using the formula suggested by Swiger *et al.*, 1964 as:

$$\text{S.E. } (h^2) = 4\sqrt{\frac{2(n-1)(1-t)^2\left[1+(k-1)t\right]^2}{k^2(n-s)(s-1)}}$$

Where,

t = intra- class correlation among paternal half sibs

s = total number of sires

n and k as described above

3.3.4 Estimation of Correlation between Body Weights and Body Measurements

Genetic, phenotypic and environmental correlations were calculated by using paternal half sib method (Becker, 1975) with the help of SPAB 2.0 (Sethi, 2002). For estimating the genotypic correlations the data corrected for the non-genetic factors were used. The minimum numbers of progeny to qualify for inclusion was assumed to be five. The models and procedures used for the analysis of variance were the same as that used for the estimation of heritability. The analysis of covariance (ANACOVA) was

Sources of variation	d.f.	Mean cross products	Expected mean cross products
Sires	s-1	MCP_s	COV_w+k COV_s
Progeny within sires	n-s	MCP_w	COV_w

where,

s = total number of sires

n = total number of progeny

For estimating Cov_s:

$$Cov_s = \frac{MCPs - MCPw}{k}$$

Where k is the same as that used in the estimation of heritability.

The genetic correlation was then calculated as

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

Where

$\sigma^2 s(x)$ = Variance between sires for the trait x

$\sigma^2 s(y)$ = Variance between sires for the trait y

The standard error of genetic correlation was calculated by using the formula

S.E.($r_{G(xy)}$) $= \left(1-r_G{}^2\right)\sqrt{\dfrac{S.E.h^2(x).S.E.h^2(y)}{2h^2(x)h^2(y)}}$

The phenotypic correlation was calculated as:

$r_{p(xy)}$ $= \dfrac{Cov_s + Cov_w}{\sqrt{\left(\sigma^2 w(x)+\sigma^2 s(x)\right)\left(\sigma^2 w(y)+\sigma^2 s(y)\right)}}$

Where

$\sigma^2 w(x)$ = Variance within sires for the trait x

$\sigma^2 w(y)$ = Variance within sires for the trait y

The standard error of phenotypic correlation was calculated by using the formula

S.E.($r_{p(xy)}$) $= \sqrt{\dfrac{1-r_{p(xy)}{}^2}{n-2}}$

3.3.5 Estimation of Genetic Correlation of Peak Yield with Body Weight and Body Measurements

Genetic correlation of peak yield was estimated with body weight and measurement by cross covariance of offspring and progeny. The formula used was as per Hazel (1943).

$r_{GiGj} = \sqrt{\dfrac{b_{i_2 j_1} b_{j_2 i_1}}{b_{i_2 i_1} b_{j_2 j_1}}}$

where,

b_{i2j1} =regression coefficient of i_2 on j_i

b_{j2i1} = regresion coefficient of j_2 on i_1

b_{i2i1} =regression coefficient of i_2 on i_i

b_{j2j1} =regression coefficient of j_2 on j_i

i_2 and i_1 are traits of dam and j_2 and j_1 are traits of progeny

3.3.6 Estimation of Phenotypic Correlation of Peak yield with Body Weight and Body Measurements

The phenotypic correlation between two traits was estimated by the formula (Falconer and Mackay,1996)

$$r_p = \frac{Cov(P_1 P_2)}{\sigma P_1 \sigma P_2}$$

where,

Cov (P_1P_2) is the phenotypic covariance between two traits

σ $P_1$and σ P_2 are the phenotypic standard deviations of the traits

Significance of correlations were tested as per Snedecor and Cochran (1994).

3.3.7 Prediction of Body Weight

Prediction equations were calculated using the multiple regression formulae (Snedecor and Cochran, 1994), which gave the best results on a preliminary analysis. Within each group body weight was regressed on different body measurements using the SPSS package. Stepwise regression procedure was carried out to determine the combination of body measurements that could explain the maximum variation in the dependent variable, the body weight. Separate prediction equations were developed for male and females as well as for singles, twins, and triplets. In addition to these, different prediction equations were developed for three centres under the AICRP.

To determine the best fitted regression equation, the coefficient of multiple determinations was used. The prediction bias was estimated using sample average ($D_i = W_i - \hat{W}_i$ (i = 1 to n) and the significance of prediction bias was tested by paired‘t’ test (Mayaka *et al.*, 1995).

3.3.8 Selection Indices

3.3.8.1 Estimation of Genotypic and Phenotypic Variance and Covariance Matrices

Genotypic and phenotypic variance- covariance matrices were derived with help of SPAB 2.0 (Sethi, 2002). Selection indices were constructed separately for the males, females, singles, twins and pooled data. Accordingly different matrices were used.

3.3.8.2 Estimation of Relative Economic Values

Relative economic values were calculated according to the method presented by Singh *et al.* (1969). The relative economic value of all the traits were calculated by taking into consideration the amounts of feed and fodder fed per head per day to the various categories of animals, their monthly labour, supervisory and monthly charges. For this purpose the animals were categorized as kids (up to three months of age) and young stock (three to six months of age). Relevant information was collected for a period from August 2005 to August 2008. Information on such items as the amount of grass grazed in the pasture, expenses on housing and shelter provided, and medicinal charges of goats were not directly available and not collected. Appropriate cost for different varieties of feed and fodder fed during the period to the various categories of animals were calculated. To these, the labour charges calculated separately for each category of animals were added. The organization of labour was such that one labourer was engaged for every 50 animals.

Cost for feed and fodder during the period (2005-2008) were as given below.

Average cost of kid starter =Rs.10.56/kg

Average cost of concentrate feed =Rs.7.94/kg

Average cost of fodder=Rs.0.75/kg

Average quantity of milk fed to a kid based on its body weight during the period of first three months was calculated as 587gms/day. The cost of milk was calculated from the rates at which the milk was sold at different periods.

Average cost of milk worked out to be Rs.14.13/kg.

The relative economic value of a trait is the value of one unit in comparison to the cost of one kg body weight at sixth month. The relative economic value of six month body weight kept at unity as the main objective of constructing selection indices was to bring about maximum improvement in sixth month body weight. The relative economic value for body length, height at withers and chest girth at below one, three and six months of age and body weight at below one month were estimated on the basis of simple regression of sixth month body weight on these traits. The relative economic value of third month body weight was calculated as the ratio of cost value for per unit body weight of kids at three months of age and cost per unit of body weight at sixth month. The economic value of peak milk yield was taken as the selling price of milk.

3.3.8.3 Construction of Various Selection Indices Using Body Weights and Body Measurements up to Six Months of Age

Selection indices were constructed by combining the body weight, chest girth, body length and height at withers at below one, three and six months of age in various combinations according to the construction of Smith's discriminant function (1936).

Animals vary in breeding value, as in phenotype, for each of the several traits. The aggregate value of an animal is the sum of its several genotypes (assuming a distinct genotype for each economic trait), each genotype being weighted according to the relative economic value of that trait. An animal's genotype for a given trait may be defined as the sum of the average (strictly additive) effects of its genes which influence that trait. Thus Smith (1936) defined the genetic worth (H) of an individual as

$$H= a_1G_1+a_2G_2+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+a_nG_n$$

where $G_1, G_2\ldots\ldots\ldots\ldots\ldots\ldots G_n$ are the genotypic values of individual characters and $a_1,a_2,\ldots\ldots\ldots\ldots a_n$ signify their relative economic importance.

Environmental factors, dominance, and epistasis may make phenotypic performance unlike the genotype for that trait; hence animals having the highest values for H cannot be recognized directly with perfect accuracy. Selection for improved breeding value therefore must be practiced indirectly by selecting directly for a correlated variable (I) based on the phenotypic performance of each animal for the several traits. So function I is defined as

$$I= b_1P_1+b_2P_2+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+b_n P_n$$

Where b_1, b_2, ……………………..b_n are unknown coefficients to be determined; in such a manner that the function I may best discriminate those individuals with good genotypes from the undesirable ones. The principle of determining b_i's therefore is that the correlation r_{IH} between I and H is a maximum. For this the normal simultaneous equations for the traits were set up as:

$$\sum_{i=1}^{n} b_i P_{ij} = \sum_{i=1}^{n} a_i G_{ij}$$

$$\text{ie} \quad Pb=Ga$$

$$b=P^{-1}Ga$$

where,

P= (P_{ij}) is the phenotypic variance-covariance matrix

G=(G_{ij}) is the genotypic variance-covariance matrix

b= the column vector of regression coefficients

a= the column vector of economic values

Thus the selection index was then constructed as

$I= b_1x_1+b_2x_2+$…………………………$+b_n\ x_n$ where b_1, b_2, ……………………..b_n are the weighting factors determined from the normal equations and x_1, x_2, ……………………..x_n represents the traits. Selection is carried out at five percent intensity.

Correlation between I and H is estimated as:

$$r_{IH} = \frac{a'Gb}{\sqrt{(b'Pb)(a'Ga)}}$$

Expected aggregate economic genetic gain is estimated by

$$\triangle G= \frac{i * a'Gb}{\sqrt{b'Pb}}$$

where,

i= intensity of selection

The genetic gain in individual characters was calculated using the formula:

$$\triangle x_i = \frac{i * Gb}{\sqrt{a'Gb}}$$

where,

i= intensity of selection

Relative efficiency of index was calculated as per Hogsett and Nordskog (1958).

$$\text{Relative efficiency} = \frac{\Delta G(I_1)}{\Delta G(I_N)}$$

Where I_1 is the index whose relative efficiency is to be estimated and I_N is the standard index with maximum aggregate genetic economic gain.

Indices were constructed using the data adjusted for non genetic factors. For indices in each category *i.e.* sex wise and type of birth wise adjustments were not made for the respective factors.

3.3.8.4 Restricted Selection Indices

Restricted selection indices were constructed according to the method of Kempthorne and Nordskog (1959) by using the body weights and body measurements at below one, three and six months of age. Restriction was imposed on body weight at below one month of age.

The principle underlying the construction of restricted selection indices is to maximize the aggregate economic genetic value based on n characters, subject to the constraints that the genotypic value of r (<n) characters do not change.

The estimates of b_i values which maximize the correlation between I and H and at the same time do not allow any change in the restricted variable is obtained by the following formula:

$$b = [I_{nn} — P^{-1}GC(C^{'}GP^{-1}GC)^{-1}C^{'}G]P^{-1}Ga$$

where,

I_{nn} is the n×n unit matrix

P^{-1} is the inverse of phenotypic variance and covariance matrix

G is the genotypic variance and covariance matrix

C is the coefficient vector matrix

and $C^{'}$ is the transposed coefficient vector

The r_{IH} values as well as the genetic gain for individual traits were calculated as described above.

3.3.8.5 Construction of Selection Indices Using Dam's Peak yield and Body Weight and Body Measurement of progeny.

Selection indices involving dam's peak yield are constructed by path coefficient method by Hazel (1943). The genetic and phenotypic correlation between dam's peak yield and body weight as well as body measurements in the progeny were already estimated. In this regression coefficients may be calculated from n simultaneous equations

$$\beta_1 + \beta_2 r_{x1\,x2} + \ldots\ldots\ldots\ldots\ldots\ldots + \beta_n r_{x1xn} = r_{x1H}$$

$$\beta_1 r_{x1\,x2} + \beta_2 + \ldots\ldots\ldots\ldots\ldots\ldots + \beta_n r_{x2xn} = r_{x2H}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\beta_1 r_{x1\,xn} + \beta_2 r_{x2xn} + \ldots\ldots\ldots\ldots\ldots\ldots + \beta_n = r_{xnH}$$

where $\beta_i = b_i * \frac{\sigma x}{\sigma H}$ and r_{XiH} is the correlation between H and the i-th phenotypic measurement.

The method of path coefficients is convenient for calculating the more complex correlations between H and phenotypic performance (r_{XiH}). This correlation is the sum of the various paths from Xi to H, as follows,

$r_{X1H} = r_{GiXi}\{d_1 r_{G1Gi} + d_2 r_{G2Gi} + \ldots\ldots\ldots\ldots\ldots\ldots + d_n r_{GnGi}\}$

where,

$r_{GiXi} = \sigma_{Gi} / \sigma_{Xi} = g_i = h$

$d_i = a_i \sigma_{Gi} / \sigma_H$

σ_{Gi} = genetic variability

σ_{Xi} = phenotypic variability

σ_H = standard deviation of breeding value

$$= \sqrt{a_1^{\,2}\sigma G_1^{\,2} + a_2^{\,2}\sigma G_2^{\,2} + \ldots + 2a_1 a_2 \sigma G_1 \sigma G_2 r_{G1G2} + \ldots}$$

r_{XiXj} = phenotypic correlation

r_{GiGj} = genotypic correlation between different traits

To construct the selection indices using the productivity of the dam, the lapse of one generation is compensated by multiplying r_{XiH} by one-half.

The r_{IH} value is calculated as per Hazel, 1943.

$r_{IH} = \sqrt{\sum \beta_{xi} r_{xiH}}$

RESULTS

4. RESULTS

The results obtained in the present study aimed at the construction of selection indices using body weight, body measurements, and milk production in Malabari goats are presented under the following heads:

4.1 Body weights
4.2 Body measurements
4.3 Milk production
4.4 Prolificacy
4.5 Heritability of body weight and body measurements
4.6 Correlations among body weight and body measurements
4.7 Genetic parameters of milk production
4.8 Prediction of body weight from body measurements
4.9 Selection indices

4.1 BODY WEIGHTS

4.1.1 Body Weights up to Six Months of Age

The overall mean body weights up to six months of age are presented in table 4.1. The body weights recorded were 3.12±0.11, 8.28±0.18 and 15.99±0.33 kg respectively for below one, three and six months of age.

4.1.2 Factors Affecting Body Weights

Least-squares means of body weight according to centre, sex, type of birth, year of birth and season of birth for below one, three and six months of age are presented in table 4.1.

4.1.2.1 Effect of Centre

Presented in table 4.1 are the means of body weight along with standard error according to the centre where the kids were born. Centre had significant effect on body weight at below one, three and six months of age. The mean body weights at below one month for Tellichery, Badagara and Tanur born kids were 3.02±0.12, 3.71±0.15 and 2.64±0.13 kg respectively. At three months of age the mean body weights of kids in the same order were 8.42±0.18, 9.94±0.26 and 6.48±0.22 kg. The above trend was maintained at six months of age also and the mean body weights were 15.84±0.33, 17.73±0.49 and 14.41±0.39 kg respectively. Thus kids born in Badagara weighed higher at all ages followed by Tellichery and Tanur born kids.

4.1.2.2 Effect of Sex

Least-squares means of body weight and body measurements according to sex for below one, three and six months of age are presented in table 4.1. Effect of sex was significant at all stages. Males had higher body weight at all the ages studied. The average body weights for males were 3.21±0.13, 8.50±0.20 and 16.40±0.37 kg at below one, three and six months of age respectively and for females the values were 3.03±0.12, 8.06±0.19 and15.58±0.34 kg respectively.

4.1.2.3 Effect of Type of Birth

Least-squares means of body weights according to type of birth are given in table 4.1. Type of birth had significant effect on body weight at below one and at three months of age only. Kids born as singles had higher body weight in these ages followed by twins and triplets. But this effect was not seen at six months of age. The mean body weights for singles along with standard error for below one, three and six months of age were 3.42±0.11, 9.03±0.17 and 16.48±0.34kg respectively. The corresponding values for twins were 3.16±0.09, 8.44±0.14 and 15.85±0.26 kg and for triplets the values were 2.87±0.13, 8.39±0.22 and 16.37±0.40 kg respectively. For quadruplets the averages were 3.01±0.34, 7.26±0.55 and 15.27±0.99 kg for below one, three and six months of age.

4.1.2.4 Effect of Year of Birth

Least-squares means in accordance with year of birth are presented in table 4.1. Year of birth had significant effect on body weights at third and sixth month. At three months of age, kids born in the year 2006 had higher average body weight (8.71±0.21 kg) followed by those born in 2005 (8.49±0.40 kg), 2007 (8.32±0.17 kg) and 2008 (7.59±0.24 kg). But at six months of age the above order was changed and those born in 2005 (17.39±0.66 kg) had higher mean body weight followed by 2006(15.72±0.36 kg), 2008 (15.61±0.59 kg) and 2007 (15.25±0.30 kg).

4.1.2.5 Effect of Season

Least-squares means according to season are presented in table 4.1. Effect of season was significant for body weight at below one and three months of age but was non significant at six months of age. Malabari kids born in summer registered higher body weight than those born in winter and rainy season at below one, three and six months of age and the mean body weight for summer born kids were 3.27±0.13, 8.90±0.22 and 16.43±0.39 kg respectively. At below one month, the mean body weight of kids born in rainy season (3.14±0.13 kg) had higher values than those born in winter (2.94±0.12 kg) and at three months of age the above order was reversed and the mean body weights were 8.19±0.20 kg and 7.75±0.23 kg for winter and rainy season born kids respectively.

4.2 BODY MEASUREMENTS

4.2.1 Body Measurements up to Six Months of Age

The overall mean of chest girth at below one, three and six month of age are presented in table 4.2. The values were 35.47±0.45, 46.12±0.46 and 56.67±0.58 cm respectively. The overall mean of body length are presented in table 4.3 and the values were recorded as 32.49±0.50, 42.30±0.46 and 50.51±0.63 cm in the same order. Presented in the table 4.4 are the overall mean heights at withers at below one, three and six months of age and the values were 35.67±0.46, 45.17±0.45 and 55.32±0.58 cm respectively.

4.2.2 Factors Affecting Body Measurements

Least square means of chest girth, body length and height at withers in accordance with centre, sex, type of birth, year of birth and season of birth for below one, three and six months of age are presented in tables 4.2, 4.3 and 4.4 respectively.

4.2.2.1 Effect of Centre

Least-squares means of chest girth, body length and height at withers according to centre for below one, three and six months of age are presented in table 4.2, 4.3 and 4.4 respectively. Locality had significant effect on body measurements at below one, three and six months of age. Badagara born animals had higher body measurements in all the age groups followed by Tellichery and Tanur born kids, except for body length at sixth months. For body length at six months of age, the Tellichery kids had higher mean (53.39±0.62 cm) followed by Badagara (50.09±0.93 cm) and Tanur born (48.04±0.73 cm) kids.

4.2.2.2. Effect of Sex

Least-squares means of chest girth, body length and height at withers according to sex for below one, three and six months of age are presented in tables 4.2, 4.3 and 4.4 respectively. Males recorded higher body measurements at all ages studied.

4.2.2.3 Effect of Type of Birth

Least-squares means of chest girth, body length and height at withers according to type of birth are given in tables 4.2, 4.3 and 4.4 respectively. Type of birth had significant effect on body measurements at below one and three months of age. But the effect of type of birth was found to be non-significant in the body measurements at six months of age except for body length. As in the case of body weight, kids born as singles had higher body measurements followed by twins, triplets and quadruplets at below one, three and six months of age except for chest girth and height at withers at six months.

4.2.2.4 Effect of Year of Birth

Least-squares means of chest girth, body length and height at withers in accordance with year of birth are presented in tables 4.2, 4.3 and 4.4 respectively. Year of birth had significant effect on body measurements at all age groups. Kids born in the year 2005 had higher mean for all the three measurements at below one, three and six months of age. The body measurements for those born in the year 2008, 2007 and 2006 showed only minor deviations.

4.2.2.5 Effect of Season

Presented in tables 4.2, 4.3 and 4.4 are the means of body measurements along with standard error in accordance with season of birth. Season of birth had significant effect on body measurements at below one, three and six months of age. In all the age groups summer born kids had higher body measurements compared to the winter and rainy season born kids. Next to summer born kids, those born in rainy season had higher averages for body measurements followed by winter born kids at below one and three months of age. But at six months of age, winter born kids were found to be having higher average body measurements compared to those born in rainy season.

4.3 MILK PRODUCTION

Milk production in Malabari goats recorded as peak yield and different factors affecting peak yield are presented in table 4.5.

4.3.1 Peak Yield in Malabari Goats

The overall mean peak yield is presented in table 4.5. The mean peak yield recorded was 1237.62±75.44 ml.

4.3.2 Factors Affecting Milk Production in Malabari Goats

Least-squares means of peak yield of Malabari goats in accordance with centre, year and season of kidding are presented in table 4.5.

4.3.2.1 Effect of Centre

Least-squares means in accordance to centre are presented in table 4.5. The effect of locality was found to be significant. Badagara animals yielded more milk (1978.28±113.60 ml) compared to the Tellichery and Tanur animals. Among the Tellichery and Tanur animals, Tellichery animals had a slightly higher average value (916.60±73.32 ml) than Tanur animals (817.97±86.05 ml), the difference being non-significant.

4.3.2.2 Effect of Year of Kidding

Least-squares means in accordance with year of kidding are presented in table 4.5. Year of kidding had significant influence on the peak yield of Malabari goats. The animals kidded in the year 2008 had higher average peak yield (1370.71±102.12 ml) followed by those in 2007 (1356.20±44.04 ml), 2006 (1165.31±51.55 ml) and 2005 (1058.23±265.13 ml).

4.3.2.3 Effect of Season of Kidding

Least-squares means in accordance with season of kidding are presented in table 4.5. Season of kidding also played a significant role in the peak yield of Malabari goats. The animals kidded in the winter season registered the highest mean peak yield (1400.40±77.37 ml). This was followed by those kidded in summer season (1204.39±80.98 ml) and rainy season (1108.06±87.69 ml).

4.4 PROLIFICACY

The percentage of singles, twins, triplets and quadruplets for Malabari goats born during the period and for different Malabari goat populations of Tellichery, Badagara and Tanur are presented in table 4.6.

The percentage of singles, twins, triplets and quadruplets were 24.29, 61.47, 13.19 and 1.05 respectively in the total population under study during the period for Malabari goats. The percentage of multiple births was higher in Tanur (79.39%) than in Badagara (74.87%) and Tellichery (74.56%).

4.5 HERITABILITY OF BODY WEIGHT AND BODY MEASUREMENTS

The heritability (h^2) of body weights and body measurements at below one, three and six months of age are presented in table 4.7.

4.5.1 Heritability of Body Weight up to Six Months of Age

The heritability of body weights at below one, three and six months of age are presented in table 4.7. The heritability along with standard error of body weights at below one, three and six months of age were 0.636±0.436, 0.023±0.229 and 0.799±0.476 respectively.

4.5.2 Heritability of Body measurements

The heritability (h^2) of body measurements at below one, three and six months of age are presented in table 4.7. For body measurements at below one and six months of age, heritability estimates were high whereas for three month of age they were low to moderate.

For chest girth the heritability estimate for below one, three and six months were 0.988±0.515, 0.028±0.220 and 0.991±0.515 respectively.

Estimated heritability for height at withers at below one, three and six months of age were 0.658±0.441, 0.064±0.245 and 0.953±0.508 respectively.

The heritability estimate for body length at below one, three and six month of age were 0.687±0.449, 0.442±0.380 and 0.845±0.486 respectively.

4.6 CORRELATIONS AMONG BODY WEIGHT AND BODY MEASUREMENTS

The genetic correlations among body weights and body measurements are presented below the diagonal in table 4.7. The phenotypic correlation estimates among body weight and body measurements at below one, three and six month of age are presented above the diagonal in table 4.7.

4.6.1 Genetic Correlation

4.6.1.1 Genetic Correlation among Body Weights

The genetic correlations among body weights are presented in table 4.7. The genetic correlation between body weights at three and six months of age were negative where as the genetic correlation of body weights between below one and six months of age was high and positive (0.817±0.150). The estimated value for genetic correlation between body weights at below one and three months of age exceeded the theoretical limit.

4.6.1.2 Genetic Correlation among Body Measurements

The genetic correlations between body measurements are presented in table 4.7. Some of the genetic correlations among body measurements were above one and all others were positive. Genetic correlations among body measurements within the age group were high and ranged from 0.526±0.929 (body length and height at withers at three months of age) to 0.952±0.037 (between body length and height at withers at six months of age). Between different age groups the genetic correlations among body measurements were positive but they were low (0.075±0.494) to high (0.990±0.020).

4.6.1.3 Genetic Correlation between Body Weights and Body Measurements

The genetic correlations between body weights and body measurements are presented in table 4.7. The estimates were above one in a few cases. Positive genetic correlations were obtained among body weights and body measurements. The correlation ranged from 0.060±02.049 (body length and weight at three months) to

0.985±0.012 (body length and body weight at sixth months). High positive genetic correlations were obtained for body weight at six months of age to the corresponding chest girth (0.934±0.050) and body length (0.985±0.012). Moderate correlations were observed with body weight at six months of age and body measurements at below one month of age.

4.6.2 Phenotypic Correlations

4.6.2.1 Phenotypic Correlation among Body Weights

The phenotypic correlation estimates among body weight at below one, three and six months of age are presented in table 4.7. Phenotypic correlation between body weight at below one and three months of age were highest (0.412±0.098) followed by the correlation between third and sixth months' body weight (0.332±0.102). The least correlation among body weights was seen between below one and six months of age (0.265±0.104).

4.6.2.2 Phenotypic Correlation among Body Measurements

The phenotypic correlation estimates among body measurements at below one, three and six months of age are presented in table 4.7. Phenotypic correlations among body measurements were positive and ranged from 0.078±0.108 (chest girth at below one and sixth months) to 0.833±0.060 (between body length and chest girth at six months of age).

4.6.2.3 Phenotypic Correlation between Body Weights and Body Measurements

The phenotypic correlation estimates between body weight and body measurements at below one, three and six months of age are presented in table 4.7.

The phenotypic correlations ranged from 0.187±0.106 to 0.718±0.075. The phenotypic correlations between body measurements within an age group were higher in below one, three and six months of age and ranged from 0.596± 0.087 to 0.718±0.075.

4.7 GENETIC PARAMETERS OF MILK PRODUCTION

4.7.1 Heritability of Peak Yield

Heritability of peak yield obtained was found to be 0.846±0.561.

4.7.2 Genetic Correlations

4.7.2.1 Genetic Correlation between Peak Yield and Body Weight

Genetic correlation coefficients between peak yield and body weights estimated by cross covariance method are presented in table 4.8. Genetic correlation coefficients estimated between body weight and peak yield were positive and the highest estimate was obtained with body weight at three months (0.88) followed by six months (0.44) and below one month body weight (0.39).

4.7.2.2 Genetic Correlation with Peak Yield and Body Measurements

Genetic correlation coefficients between peak yield and body measurements are presented in table 4.8. Genetic correlation coefficients estimated between body measurements and peak yield were positive and they ranged from 0.08 (for chest girth at sixth months and peak yield) to 0.87 (for peak yield and height at withers at below one month).

4.7.3 Phenotypic Correlations

4.7.3.1 Phenotypic Correlation between Peak Yield and Body Weight

Phenotypic correlations between peak yield and body weight are presented in table 4.8. Positive phenotypic correlations between peak yield and body weight were seen at below one month (0.10) and six months (0.13) but the value was lowest with three month's body weight (0.08).

4.7.3.2 Phenotypic Correlation between Peak Yield and Body Measurements

Presented in table 4.8 are the phenotypic correlations between peak yield and body measurements at below one, three and six months of age. The values were positive except for chest girth (-0.08) and body length (-0.01) at six months of age. The values ranged between 0.01 (for both chest girth and body length at three months of age and peak yield) and 0.15 (height at withers at below one month and peak yield).

4.8 PREDICTION OF BODY WEIGHT FROM BODY MEASUREMENTS

Table 4.9, 4.10 and 4.11 detailed the output of multiple linear regression equations for the prediction of body weight at below one month, three and six months of age respectively along with coefficient of determination (adjusted R^2values).

4.8.1 Prediction Equations for Below One Month

Presented in the table 4.9 are the prediction equations for below one month of age for females, males, singles, twins and triplets as well as for three centres and for the pooled data. The adjusted R^2 for different equations for this age ranged from 0.236 to 0.583.

For females and males the best fitted prediction equations were

$Y = -1.300 + 0.056\ X_3 + 0.063X_1$(adjusted $R^2 = 0.364$) and

$Y = -0.822 + 0.067X_1 + 0.035X_4$ (adjusted $R^2 = 0.277$) respectively.

The best fitted regression output for singles, twins and triplets were

$Y = -1.367 + 0.071X_2 + 0.048X_3$ (adjusted $R^2 = 0.386$),

$Y = -0.747 + 0.057X_4 + 0.042X_2$ (adjusted $R^2 = 0.259$) and

$Y = 0.399 + 0.064X_3$ (adjusted $R^2 = 0.237$) respectively.

For Tellichery, Badagara and Tanur the best fitted prediction equations were

$Y = -2.024 + 0.103X_1 + 0.38X_3$,

$Y = -3.905 + 0.139X_2 + 0.054X_4$ and

$Y = -0.484 + 0.051X_2 + 0.049X_1$ respectively with an adjusted R^2 varied from 0.339 to 0.583.

The best fitted regression model for pooled data was

$Y = -1.183 + 0.062X_1 + 0.028X_3 + 0.025X_4$ with an adjusted R^2 of 0.319.

4.8.2 Prediction Equations for Three Months

The prediction equations for three months of age for females, males, singles, twins, triplets as well as for three centres and for pooled data, are presented in table 4.10.

The best fitted prediction equations for females and males were

$Y = -9.997 + 0.328X_1 + 0.086X_3$ and

$Y = -11.925 + 0.325X_1 + 0.096X_4 + 0.074X_2 + -0.057X_3$

with adjusted R^2 of 0.694 and 0.786 respectively.

For singles, twins and triplets, the best fitted regression output were

$Y = -9.626 + 0.347X_1 + 0.056X_4$ (adjusted $R^2 = 0.660$),

$Y = -11.808 + 0.262X_1 + 0.109X_4 + 0.066X_2$ (adjusted $R^2 = 0.773$) and

$Y = -11.819 + 0.448X_1$ (adjusted $R^2 = 0.733$) respectively

The best fitted prediction equations for Tellichery, Badagara and Tanur at three months of age were

$Y = 8.526 + 0.220X_1 + 0.097x4 + 0.055X_2$,

$Y = -8.517 + 0.299X_1 + 0.079X_3$ and

$Y = -4.814 + 0.288X_1$ with adjusted R^2 0.670, 0.613 and 0.519 in the same order.

The best fitted regression model for pooled data was

$Y = -10.920 + 0.309X_1 + 0.075X_4 + 0.040X_2$ with an adjusted R^2 of 0.715.

4.8.3 Prediction Equations for Six Months

Presented in table 4.11 are the prediction equations for six months old females, males, singles, twins, triplets and for pooled data. Centre wise prediction equations are also presented in table 4.11 for six months of age. The adjusted R^2 for different equations for this age ranged from 0.496 to 0.734.

For females and males the best fitted prediction equations were

$Y = -12.670 + 0.344X_1 + 0.166X_4$ (adjusted $R^2 = 0.669$) and

$Y = -10.662 + 0.285X_1 + 0.189X_4$ (adjusted $R^2 = 0.603$) respectively.

The best fitted regression output for singles, twins and triplets were

$Y = -13.031 + 0.349X_1 + 0.166X_4$ (adjusted $R^2 = 0.612$),

$Y = -8.436 + 0.280X_1 + 0.156X_4$ (adjusted $R^2 = 0.632$) and

$Y = -12.985 + 0.512X_1$ (adjusted $R^2 = 0.734$) respectively.

For Tellichery, Badagara and Tanur the best fitted prediction equations were

$Y = -14.230 + 0.348\ X_1 + 0.190\ X_3$,

$Y = -10.583 + 0\ .298X_1 + 0.172\ X_4$ and

$Y = -15.363 + 0.292\ X_1 + 0.281\ X_4$ respectively with adjusted R^2 of 0.672, 0.527 and 0.579.

The best fitted regression model for pooled data was

$Y = -11.624 + 0.328X_1 + 0.164X_4$ with an adjusted R^2 of 0.634.

4.8.4 Prediction Accuracy

The predicted weights and predicted bias for predicted weight in the best fitted equation in each group are presented in Table 4.12. Predicted bias was non- significant in all cases.

4.9 SELECTION INDICES

4.9.1 Estimation of Relative Economic Value

Cost/head/day (Rs) for rearing kids up to six months of age was calculated and are presented in the table 4.13. The relative economic values of all the traits are presented in table 4.14. The relative economic value of body weight at three months of age was highest (1.3100) followed by body weight at six months of age (1.0000). The relative economic value of peak yield was 0.1547.

4.9.2 Selection Indices Involving Body Weights and Body Measurements

4.9.2.1 Sex Wise Selection Indices

4.9.2.1.1 Selection Indices for Males

Various selection indices were constructed using body weight and body measurements at below one, three and six months of age as traits and are presented in table 4.15. The index containing all the traits was:

$I=-0.9764X_1+ 0.9586X_2 + 0.5438X_3 -0.1596 X_4+ 0.1256X_5 + 0.1313X_6 -0.4968 X_7 -0.6303X_8 + 02.5539 X_9+ 0.2888 X_{10} +0.2339X_{11} -0.6850X_{12}$

The r_{IH} value of each selection index is noted against it in table 4.15. The lowest r_{IH} value (0.4696) for the index was for those involving only two variables and the index was

$I=0.2223X_1+ 0.0845X_2.$

The highest r_{IH} value of 0.8267 was for the index involving all the traits.

The total genetic gains in terms of economic value of the traits as a result of application of a particular selection index have been noted in table 4.15. The eleventh index had the highest genetic gain of 6.3573 followed by tenth index with a value of 5.7460. The genetic gain increased as number of traits increased.

The genetic gains expected in the traits as a result of a particular selection index for males are presented in table 4.16. Maximum genetic improvement in body weight at six months of age (0.364 kg) was expected with the use of the eleventh index. The sixth index showed lowest genetic gain (0.181 kg) for body weight at six months of age.

The eleventh index which incorporated maximum number of traits was assigned 100% efficiency for predicting response to selection. The relative efficiencies were evaluated on the basis of aggregate economic genetic gain and are presented against each index in table 4.15. The tenth index had highest efficiency (90.38%). It was followed by the ninth index (85.51%). The relative efficiencies ranged from 21.73 to 90.38%.

4.9.2.1.2 Selection Indices for Females

Different selection indices constructed for females are presented in table 4.17. A total of eleven indices were constructed using twelve economically important traits. The selection index for females involving all the traits was:

$I=0.6393\ X_1\ -0.1980X_2\ \ -0.0709\ X_3+\ 0.6245X_4 + 01.7306X_5\ \ -0.2740X_6\ \ -0.5038X_7\ \ -0.0417X_8 + 05.0545X_9\ \ -0.6293X_{10} + 0.3482X_{11}\ \ -0.6915X_{12}$

The r_{IH} values are presented against each index in table 4.17. The r_{IH} values ranged from 0.3393 to 0.9881. The lowest r_{IH} value was for the index involving two variables ($I= 0.0619X_1 + 0.060X_2$). The third index ($I= 0.3371X_1\ -0.1179X_2\ -0.3905\ X_3+\ 0.6357X_4$) having variables body weight and body measurements at six months of age had higher r_{IH} values than indices

$I= 0.4458\ X_1\ -0.2578X_2\ -0.3259X_3+\ 0.5819\ X_4 +0.5814X_5$ and $I= 0.4164X_1\ -0.2087X_2\ - 0.4011X_3+\ 0.7363X4 + 0.6010X_5\ -0.1120X_6$

which involved body weight, chest girth and height at withers of three months of age along with traits at six months of age.

The aggregate economic genetic gain of each index is presented against each index in table 4.17. The aggregate economic genetic gain of 0.5884 was noted for the index $I= 0.0619X_1 + 0.060X_2$ involving body weight and chest girth at six months of age, which was the lowest value. The highest value for the aggregate economic genetic gain of 6.4658 was for the index involving all the traits.

The expected genetic gains for each of the traits by the application of particular indices are presented in table 4.18. The expected genetic advance for all the traits were positive and the genetic gain for six months body weight was highest for the index 11 with twelve variables (0.826 kg). The expected genetic gain for body weight at six months was more for index 8 (0.815) than index 9 (0.748) and index10 (0.790).

Relative efficiencies of indices are presented in table 4.17. Relative efficiencies ranged from a low to high value *i.e.* 9.10 to 90.94%.

4.9.2.2 Type of Birth Wise Selection Indices

4.9.2.2.1 Selection Indices for Single Births

Selection indices were constructed for single births and are presented in table 4.19. The selection index incorporating all the traits was:

$$I= -0.5923X_1 -05.5593X_2 + 04.0386X_3 +02.7690X_4 + 03.6035X_5+ 09.9151 X_6 -06.4886X_7 -03.2629X_8 -25.8698X_9+ 0.3289 X_{10} -0.0574X_{11} + 08.1193X_{12}$$

The r_{IH} values are presented against each index in table 4.19. The r_{IH} values of indices ranged between 0.4848 and 1.9998. The r_{IH} values of indices one, two and three are within theoretical limits and the corresponding values for other indices were above the theoretical limits.

Aggregate economic genetic gains for the index were evaluated and are presented in table 4.19. The index involving all the traits had maximum aggregate economic genetic gain of 13.3635. This was followed by 11variate index (10.4993). The lowest economic genetic gain with the two variate index $I=0.2446X_1+ 0.0811X_2$ was1.4378.

Expected genetic gain in the economic characters with different selection indices are presented in table 4.20. Expected genetic gain for chest girth for three and six months turned out to be negative by the application of indices I_2, I_3, I_5, I_6, I_7, I_8 and $I_{11.}$ When selection was based on index no.11, the expected genetic gain in body weight at six months of age was highest (2.938 kg), followed by index no.8 (2.198 kg).

Relative efficiencies of indices were evaluated on the basis of aggregate economic genetic gain and are presented against each index in table 4.19. The efficiencies ranged between 10.76 and 78.57%.

4.9.2.2.2 Selection Indices for Twins

Eleven selection indices were constructed by incorporating twelve traits for twins and are presented in table 4.21. A selection index involving all the traits was:

$I= 0.1255X_1 -0.0374X_2 +0.2665X_3+ 0.1021X_4 -0.8386X_5 -0.0951X_6+ 0.5411X_7 -0.3308X_8 - 06.7760X_9 -0.4732X_{10} +0.3311X_{11}+ 0.3194 X_{12}$

The r_{IH} value of each selection index is noted against it in table 4.21. The lowest r_{IH} value (0.3631) for the index was for the index involving only two variables and the index was $I=0.1465X_1+ 0.0237X_2$. The highest r_{IH} value of 0.8205 was for the index incorporating all the traits.

The total genetic gains in terms of economic value of the traits for the particular selection index are noted in table 4.21. The eleventh index (5.1453), followed by tenth index (4.9478) had the higher gains.

The expected genetic gains expected in the traits as a result of particular selection indices are presented in table 4.22. Maximum genetic improvement in body weight at six months of age (1.008 kg) was expected with the use of eleventh index, but the application of this index caused a negative impact on the genetic gain for body weight (-0.147 kg)and chest girth (-0.544 cm) at below one month of age.

Relative efficiencies of indices are presented in the table 4.21. The eleventh index had highest efficiency (96.16%). It was followed by index no 10 (87.90 %) and index no.9 (86.04%).

4.9.2.3 Selection Indices for Pooled Data

Eleven indices were constructed using body weights and body measurements like chest girth, body length and height at withers at below one, three and six months of age from the pooled data and are presented in table 4.23.

The r_{IH} value of each selection index is noted against it in table 4.23 .The r_{IH} values ranged from 0.5226 to 0.7324. The eleventh index,

$I= 0.1222X_1 + 0.4857X_2 + 0.4635X_3 -0.3158X_4 -0.5832X_5 -0.0308X_6 -0.2979 X_7 -0.038X_8 + 01.2742X_9 + 0.106X_{10} + 0.5035X_{11} -0.2857X_{12}$, which involved all the traits, had the highest r_{IH} value.

Aggregate economic genetic gains as a result of application of particular selection indices have been noted in table 4.23. As in the case of $r_{IH,}$ the index involving all the traits had maximum aggregate economic genetic gain of 6.2974. This was followed by the 11variate index (5.9443). The lowest economic genetic gain was with the two variate index $I=0.1907X_1 + 0.1429X_2$ (1.9653).

The expected genetic gains for each trait as result of application of particular selection indices are presented in table 4.24. The expected genetic gain for each trait was positive in all cases. When selection was based on index number 11(12 variate), 10(11 variate) and 9 (10 variate), the expected genetic progress in body weight at six months of age were 1.490, 1.446 and 1.408 kg respectively.

The index involving all the twelve traits considered in this study (index no.11) was taken to be 100% efficient in genetic sense and the efficiency of rest of the indices was compared with that of this index. The relative efficiencies of particular indices are noted against each index and presented in the table 4.23. The first two indices (two variate and three variate) had moderate efficiencies. All other indices had high efficiencies varying from 53.23 to 94.39 %.

4.9.2.4 Comparison of the Best Selection Indices among Different Groups

Presented in table 4.25 are the best selection indices among males, females, singles, twins and pooled data along with their aggregate economic genetic gain, expected gain in the body weight at six months of age and their r_{IH} values. Comparison was based on the number of sires and average number of progeny per sire used in each group for the construction of selection indices. Selection indices in the pooled data used more number of sires (9) and average number of progeny per sire (9.78). Selection indices based on singles were not reliable completely as the average number of progeny per sire was less (3.75).

4.9.3 Restricted Selection Indices

Restricted selection indices were constructed by imposing restrictions on one of the traits and the expected genetic gains for individual traits by the application of particular index are presented in Table 4.26 and 4.27.

4.9.3.1 Restricted Selection Indices and Their r_{IH} Value

Separate restricted selection indices were constructed for males, females, singles, twins and pooled data by imposing restriction on body weight at below one month and are presented in table 4.26 along with their r_{IH} values.

Restricted selection index developed for males was:

I_m= -0.9696 X_1+ 0.9266X_2 +0.5446X_3-0.1419X_4+0.1093 X_5+0.1403 X_6+-0.4910 X_7-0.6138X_8+2.5505 X_9+0.2765 X_{10} +0.2441 X_{11}-0.6889 X_{12}

with a lower r_{IH} value of 0.2577.

For females a higher r_{IH} value (0.5711) was observed with the index,

I_f= -0.2196X_1 -0.1628 X_2+ 0.3810 X_3 -0.1371 X_4 +0.3032 X_5 -0.0432 X_6 -0.0839 X_7 -0.2405 X_8 +3.3348 X_9 -0.4555 X_{10} + 0.2595 X_{11} -0.2471X_{12}

For singles, the r_{IH} value estimated turned out to be negative and the index was:

$I_s = -9.7862X_1 + 2.4307X_2 + 1.7866X_3 + 5.4040X_4 + 16.0426\,X_5 - 0.1177X_6 - 4.4774X_7 - 11.2945\,X_8 - 13.0842X_9 + 3.8715X_{10} - 12.1555X_{11} + 10.4434X_{12}$

Restricted selection index developed for twins had a r_{IH} value of 0.3680 and the index was:

$I_t = -0.1811X_1 - 0.0687X_2 - 0.0066\,X_3 - 0.0230\,X_4 - 0.2363\,X_5 - 0.0422\,X_6 + 0.0068\,X_7 - 0.0876\,X8 - 5.2322\,X_9 - 0.0728\,X_{10} + 0.0249X_{11} + 0.0121X_{12}$

For the pooled data restricted selection index was:

$I_p = -0.0456X_1 + 0.1567X_2 + 0.0330X_3 + 0.1447X_4 - 0.4365X_5 - 0.0672X_6 - 0.1398\,X_7 + 0.0247X_8 + 1.4743\,X_9 - 0.1883\,X_{10} + 0.6437\,X_{11} - 0.7246\,X_{12}$

with an r_{IH} value of 0.4782.

4.9.3.2 Expected Genetic Gain for Individual Characters

The genetic gains expected in the traits as a result of particular restricted selection index are presented in table 4.27. Since restriction was imposed on body weight at below one month of age, the genetic gain for that trait was zero or near to zero. For pooled data, genetic gain expected for body weight at six month was 0.630 kg. But a negative gain was noted for body weight at three months and chest girth and body length at below one month by the application of restricted selection index for pooled data.

4.9.4 Selection Indices Involving Dam's Peak Yield, Body Weights and Body Measurements

A selection index was constructed with dam's peak yield as one of the traits together with body weight and body measurements of progeny at below one, three and six months of age and the index was:

$I=-0.4474X_1$ $-0.2057X_2$$-0.0708X_3$$+$ $0.7960X_4$$-$ $0.2434X_5$$+$ 0.1424 X_6 -0.2816 X_7 $-$ 0.3860 X_8 -7.0463 X_9 0.9467 X_{10} 0.6469 X_{11} $+0.5184X_{12}$$+0.0001X_{13}$

Where X_1, X_2, X_3 and X_4 are the body weight, chest girth, height at withers and body length at six months of age. X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11} and X_{12} are the body weight and body measurements in the same order at three and below one month of age respectively. Dam's peak yield is denoted by $X_{13.}$

This index had the r_{IH} value of 0.5703.

Table 4.1. Least-squares means of body weight (kg) of Malabari goats at below one, three and six months of age according to centre, sex, type of birth, year of birth and season of birth

Effects	At below one month		At three months		At six months	
	n	Mean±S.E	n	Mean±S.E	n	Mean±S.E
Over all	845	3.12±0.11	712	8.28±0.18	436	15.99±0.33
Centre						
Tellichery	520	$3.02{\pm}0.12^{b}$	409	$8.42{\pm}0.18^{b}$	248	$15.84{\pm}0.33^{b}$
Badagara	143	$3.71{\pm}0.15^{a}$	120	$9.94{\pm}0.26^{a}$	64	$17.73{\pm}0.49^{a}$
Tanur	182	$2.64{\pm}0.13^{c}$	183	$6.48{\pm}0.22^{c}$	124	$14.41{\pm}0.39^{c}$
Sex						
Female	407	$3.03{\pm}0.12^{b}$	345	$8.06{\pm}0.19^{b}$	231	$15.58{\pm}0.34^{b}$
Male	438	$3.21{\pm}0.13^{a}$	367	$8.50{\pm}0.20^{a}$	205	$16.40{\pm}0.37^{a}$
Type of birth						
Single	209	$3.42{\pm}0.11^{a}$	191	$9.03{\pm}0.17^{a}$	104	$16.48{\pm}0.34^{a}$
Twin	520	$3.16{\pm}0.09^{b}$	414	$8.44{\pm}0.14^{b}$	258	$15.85{\pm}0.26^{a}$
Triplet	103	$2.87{\pm}0.13^{c}$	94	$8.39{\pm}0.22^{bc}$	65	$16.37{\pm}0.40^{a}$
Quadruplet	13	$3.01{\pm}0.34^{abc}$	13	$7.26{\pm}0.55^{c}$	9	$15.27{\pm}0.99^{a}$
Year of birth						
2005	21	$3.22{\pm}0.29^{a}$	33	$8.49{\pm}0.40^{b}$	25	$17.39{\pm}0.66^{a}$
2006	266	$3.13{\pm}0.12^{a}$	232	$8.71{\pm}0.21^{a}$	194	$15.72{\pm}0.36^{b}$
2007	341	$2.98{\pm}0.10^{a}$	327	$8.32{\pm}0.17^{c}$	184	$15.25{\pm}0.30^{b}$
2008	217	$3.14{\pm}0.12^{a}$	120	$7.59{\pm}0.24^{c}$	33	$15.61{\pm}0.59^{b}$
Season of birth						
Summer	375	$3.27{\pm}0.13^{a}$	269	$8.90{\pm}0.22^{a}$	149	$16.43{\pm}0.39^{a}$
Rainy	220	$3.14{\pm}0.13^{ab}$	163	$7.75{\pm}0.23^{c}$	118	$15.68{\pm}0.41^{b}$
Winter	250	$2.94{\pm}0.12^{b}$	280	$8.19{\pm}0.20^{b}$	169	$15.86{\pm}0.38^{ab}$

Means with different superscripts differ significantly (P<0.05). n=Number of observations, SE= Standard error

Table 4.2. Least-squares means of chest girth (cm) of Malabari goats at below one, three and six months of age according to centre, sex, type of birth, year of birth and season of birth

Effects	At below one month		At three months		At six months	
	n	Mean±S.E	n	Mean±S.E	n	Mean±S.E
Over all	845	35.47±0.45	712	46.12±0.46	436	56.67±0.58
Centre						
Tellichery	520	35.21±0.45 ^{b}	409	46.36±0.46^{b}	248	57.82±0.58 ^{b}
Badagara	143	38.90±0.60 ^{a}	120	49.81±0.66^{a}	64	60.49±0.86 ^{a}
Tanur	182	32.31±0.52 ^{c}	183	42.19±0.55^{c}	124	51.70±0.68 ^{c}
Sex						
Female	407	35.00±0.48 ^{b}	345	45.57±0.49^{b}	231	55.66±0.60 ^{b}
Male	438	35.94±0.46 ^{a}	367	46.67±0.51^{a}	205	57.67±0.65 ^{a}
Type of birth						
Single	209	37.41±0.49 ^{a}	191	48.45±0.44^{a}	104	57.61±0.60 ^{a}
Twin	520	35.42±0.41 ^{b}	414	47.29±0.36^{b}	258	57.10±0.45 ^{a}
Triplet	103	34.78±0.34 ^{b}	94	46.60±0.57^{b}	65	56.58±0.70 ^{a}
Quadruplet	13	34.26±1.30 ^{b}	13	42.15±1.41^{c}	9	55.38±1.72 ^{a}
Year of birth						
2005	21	38.83±1.11 ^{a}	33	48.45±1.02^{a}	25	58.60±1.16 ^{a}
2006	266	34.58±0.47 ^{b}	232	45.92±0.53^{b}	194	54.94±0.62 ^{c}
2007	341	34.20±0.39 ^{b}	327	45.58±0.43^{bc}	184	56.18±0.53 ^{b}
2008	217	34.27±0.48 ^{b}	120	44.53±0.62^{c}	33	56.95±1.02 ^{abc}
Season of birth						
Summer	375	36.17±0.52 ^{a}	269	46.91±0.55^{a}	149	57.46±0.67 ^{a}
Rainy	220	35.67±0.52 ^{a}	163	45.90±0.59^{ab}	118	55.48±0.71 ^{b}
Winter	250	34.57±0.52 ^{b}	280	45.55±0.50^{b}	169	57.06±0.66 ^{a}

Means with different superscripts differ significantly ($P<0.05$). n=Number of observations, SE= Standard error

Table 4.3. Least-squares means of body length (cm) of Malabari goats at below one, three and six months of age according to centre, sex, type of birth, year of birth and season of birth

Effects	At below one month		At three months		At six months	
	n	Mean±S.E	n	Mean±S.E	n	Mean±S.E
Over all	845	32.49±0.50	712	42.30±0.46	436	50.51±00.63
Centre						
Tellichery	520	34.28±0.46 ^{a}	409	43.28±0.46^{a}	248	53.39±0.62 ^{a}
Badagara	143	35.25±0.62 ^{a}	120	43.40±0.64^{a}	64	50.09±0.93 ^{b}
Tanur	182	31.20±0.54 ^{b}	183	40.22±0.55^{b}	124	48.04±0.73 ^{c}
Sex						
Female	407	33.20±0.47 ^{b}	345	41.92±0.49^{b}	231	49.61±0.65^{b}
Male	438	33.96±0.50 ^{a}	367	42.68±0.50^{a}	205	51.40±0.71^{a}
Type of birth						
Single	209	35.01±0.43 ^{a}	191	44.49±0.44^{a}	104	52.43±0.65 ^{a}
Twin	520	33.29±0.35 ^{b}	414	43.23±0.36^{b}	258	51.43±0.49 ^{a}
Triplet	103	32.88±0.55 ^{b}	94	42.09±0.56^{c}	65	51.03±0.76 ^{ab}
Quadruplet	13	33.14±1.35 ^{ab}	13	39.41±1.39^{c}	9	47.13±1.86 ^{b}
Year of birth						
2005	21	32.87±0.48 ^{b}	33	44.89±1.00^{a}	25	54.18±1.25 ^{a}
2006	266	32.21±0.41 ^{a}	232	42.61±0.52^{b}	194	49.58±0.67 ^{b}
2007	341	32.79±0.49 ^{a}	327	41.75±0.43^{b}	184	49.90±0.57 ^{b}
2008	217	33.58±0.46 ^{a}	120	39.95±0.61^{c}	33	48.36±1.10 ^{b}
Season of birth						
Summer	375	36.45±1.14 ^{a}	269	42.99±0.54^{a}	149	51.44±0.73 ^{a}
Rainy	220	34.46±0.54 ^{a}	163	41.65±0.58^{b}	118	49.80±0.77 ^{b}
Winter	250	33.78±0.54 ^{b}	280	42.26±0.50^{ab}	169	50.28±0.71 ^{ab}

Means with different superscripts differ significantly ($P<0.05$). n=Number of observations and SE= Standard error

Table 4.4. Least-squares means of height at wither (cm) of Malabari goats at below one, three and six months of age according to centre, sex, type of birth, year of birth and season of birth

Effects	At below one month		At three months		At six months	
	n	Mean±S.E	n	Mean±S.E	n	Mean±S.E
Over all	845	35.67±0.46	712	45.17±0.45	436	55.32±0.58
Centre						
Tellichery	520	36.20±0.46 [b]	409	45.09±0.45[b]	248	55.75±0.58[a]
Badagara	143	37.81±0.62 [a]	120	46.89±0.63[a]	64	56.56±0.87[a]
Tanur	182	32.98±0.54 [c]	183	43.53±0.53[c]	124	53.64±0.68[b]
Sex						
Female	407	35.23±0.47 [b]	345	44.60±0.48[b]	231	54.39±0.61[b]
Male	438	36.10±0.50 [a]	367	45.74±0.49[a]	205	56.24±0.66[a]
Type of birth						
Single	209	36.88±0.43 [a]	191	47.16±0.43[a]	104	56.41±0.60[a]
Twin	520	35.65±0.35 [b]	414	46.21±0.35[b]	258	55.87±0.46 [a]
Triplet	103	35.52±0.55 [b]	94	45.90±0.55[b]	65	55.54±0.70 [a]
Quadruplet	13	34.61±1.35 [b]	13	41.41±1.36[c]	9	53.45±1.74 [a]
Year of birth						
2005	21	38.82±1.15 [a]	33	47.33±0.98[a]	25	58.45±1.17 [a]
2006	266	35.03±0.48 [b]	232	45.87±0.51[a]	194	54.24±0.62 [b]
2007	341	34.07±0.41 [c]	327	44.59±0.42[b]	184	53.70±0.53 [b]
2008	217	34.73±0.49 [bc]	120	42.89±0.60[c]	33	54.89±1.03 [b]
Season of birth						
Summer	375	36.21±0.54 [a]	269	45.93±0.53[a]	149	56.28±0.68[a]
Rainy	220	36.13±0.54 [a]	163	45.02±0.56[ab]	118	54.83±0.71[b]
Winter	250	34.45±0.50 [b]	280	44.57±0.49[b]	169	54.84±0.66[b]

Means with different superscripts differ significantly (P<0.05). n=Number of observations and SE= Standard error

Table 4.5. Least-squares means of peak yield (ml) in Malabari goats according to centre year and season of birth

Effects	Groups	n	Peak yield (milliliters)
Overall mean		146	1237.62± 75.44
Centre	Tellichery	95	916.60± 73.32[b]
	Badagara	9	1978.28 ±113.60[a]
	Tanur	42	817.97± 86.05[b]
Year	2005	1	1058.23 ±265.13[c]
	2006	87	1165.31 ±51.55[b]
	2007	51	1356.20 ±44.04[a]
	2008	7	1370.71±102.12[a]
Season	Summer	55	1204.39± 80.98[b]
	Rainy	35	1108.06± 87.69[b]
	Winter	56	1400.40 ±77.37[a]

Means with different superscripts differ significantly (P<0.05). n=Number of observations

Table 4.6. Litter size in percentage in Malabari goat populations of Tellichery, Badagara, Tanur and overall population

Sl.No	Litter size	Populations			
		Tellichery	Badagara	Tanur	Over all
1	Singles	25.44	25.13	20.61	24.29
2	Twins	61.66	63.39	60.47	61.47
3	Triplets	12.37	11.48	16.22	13.19
4	Quadruplets	0.53	-	2.70	1.05

Table 4.7. Heritability, phenotypic and genotypic correlations of body weights and body measurements with standard error at below one, three and six months of age

	BW6	CG6	HW6	BL6	BW3	CG3	HW3	BL3	BW1	CG1	HW1	BL1
BW6	**0.799± 0.476**	0.596± 0.087	0.652± 0.082	0.621± 0.085	0.332± 0.102	0.187± 0.106	0.277± 0.104	0.254± 0.104	0.265± 0.104	0.335± 0.102	0.404± 0.099	0.330± 0.102
CG6	0.934± 0.050	**0.991± 0.515**	0.725± 0.074	0.833± 0.060	0.392± 0.099	0.464± 0.096	0.451± 0.096	0.451± 0.096	0.155± 0.107	0.078± 0.108	0.298± 0.103	0.195± 0.106
HW6	1.092± -0.076	0.835± 0.113	**0.953± 0.508**	0.784± 0.067	0.316± 0.102	0.320 ± 0.102	0.517± 0.092	0.460± 0.096	0.292± 0.103	0.307± 0.103	0.476± 0.095	0.380± 0.100
BL6	0.985± 0.012	0.908± 0.068	0.952± 0.037	**0.845± 0.486±**	0.356± 0.108	0.417± 0.098	0.476± 0.095	0.531± 0.091	0.205± 0.106	0.167± 0.106	0.448± 0.096	0.350± 0.101
BW3	-0.037± 01.710	0.587± 1.049	0.272± 1.501	-1.104± -0.370	**0.023± 0.229**	0.653± 0.082±	0.599± 0.086	0.608± 0.086	0.412± 0.098	0.276± 0.104	0.359± 0.106	0.330± 0.102
CG3	-1.412± -4.832	0.626± 2.763	0.314± 4.142	-2.658± -28.959	-1.956± -55.852	**0.028± 0.220**	0.805± 0.064	0.719± 0.075	0.372± 0.101	0.223± 0.105	0.303± 0.103	0.292± 0.103
HW3	0.252± 1.012	0.176± 0.968	0.655± 0.577	0.137± 1.031	- 3.67± -53.824	3.345± -125.69	**0.064± 0.245**	0.733± 0.073	0.359± 0.106	0.297± 0.103	0.436± 0.097	0.390± 0.099
BL3	0.190± 0.487	0.095± 0.468	0.469± 0.373	0.075± 0.494	0.060± 02.049	0.630 ± 03.520	0.526± 0.929	**0.442± 0.380**	0.462± 0.096	0.331± 0.102	0.478± 0.095	0.425± 0.098
BW1	0.817± 0.150	0.490± 0.321	0.771± 0.173	0.364± 0.385	1.596± -2.839	2.856± -37.261	1.015± -0.034	0.375± 0.466	**0.636± 0.436**	0.718± 0.075	0.603± 0.086	0.662± 0.081
CG1	0.578± 0.262	0.383± 0.314	0.635± 0.222	0.454± 0.307	0.859± 0.421	2.576± -25.615	0.990± 0.020	0.574± 0.317	1.016± -0.014	**0.988± 0.515**	0.682± 0.079	0.639± 0.083
HW1	1.034± -0.031	0.777± 0.166	1.132± -0.119	0.775± 0.176	1.373± -1.609	2.846± -36.629	1.160± -0.392	0.773± 0.216	1.014± -0.013	0.847± 0.118	**0.658± 0.441**	0.830± 0.060
BL1	0.570± 0.298	0.281± 0.379	0.567± 0.283	0.119± 0.428	2.356± -8.166	2.205± -19.559	0.464± 0.878	0.522± 0.386	1.149± -0.152	1.053± -0.045	0.810± 0.161	**0.687± 0.449**

Heritability on the diagonal, phenotypic correlations above diagonal and genotypic correlations below the diagonal BW6-body weight at six months of age, CG6- chest girth at six months of age, HW6- height at wither at six months of age, BL6- body length at six months of age, BW3-body weight at three months of age, CG3- chest girth at three months of age, HW3- height at wither at three months of age, BL3- body length at three months of age, BW1-body weight at below one month of age, CG1- chest girth at below one month of age, HW1- height at wither at below one month of age, BL1- body length at below one month of age

Table 4.8. Genotypic and phenotypic correlation coefficients of peak yield to body weight and body measurements at below one, three and six month of age

Correlation coefficient	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Genotypic correlation	0.44^{**}	0.08	0.35^{**}	0.47^{**}	0.88^{**}	0.76^{**}	0.42^{**}	0.22^{**}	0.39^{**}	0.82^{**}	0.87^{**}	0.57^{**}
Phenotypic correlation	0.13	- 0.08	0.08	-0.01	0.08	0.01	0.04	0.01	0.10	0.11	0.15	0.14

**significant at 1%level

X_1=body weight at six month, X_2= chest girth at six month, X_3= height at wither at six month, X_4= body length at six month, X_5= body weight at three month, X_6=chest girth at three month, X_7= height at wither at three month, X_8= body length at three month, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month and X_{12}= body length at below

Table 4.9. Prediction equations and coefficient of determination (adjusted R^2) for predicting body weight from body measurements at below one month

Groups	Equation	Adjusted R^2
Female	$Y= -0.442+0.094\ X_3$	0.312
	$Y= -1.300+ 0.056\ X_3+ 0.063X_1$	0.364
Male	$Y= -0.679+ 0.098X_1$	0.248
	$Y= -0.822+ 0.067X_1+ 0.035X_4$	0.277
Single	$Y= -1.083+ 0.105X_2$	0.339
	$Y= -1.367+ 0.071X_2+ 0.048X_3$	0.386
Twin	$Y= -0.191+ 0.0805X_4$	0.236
	$Y= -0.747+0.057X_4+0.042X_2$	0.259
Triplet	$Y= 0.399+ 0.064X_3$	0.237
Tellichery	$Y= -1.803+0.133X_1$	0.317
	$Y= -2.024+0.103X_1+0.38X_3$	0.339
Badagara	$Y= -3.285+0.173X_2$	0.538
	$Y= -3.905+0.139X_2+0.054X_4$	0.583
Tanur	$Y= 0.020+0.082X_2$	0.356
	$Y= -0.484+0.051X2+0.049X_1$	0.399
Pooled	$Y= -0.861+0.103\ X_1$	0.280
	$Y= -1.051+0.071X_1+0.040X_3$	0.311
	$Y= -1.183+0.062X_1+0.028X_3+0.025X_4$	0.319

Y= body weight, X_1=chest girth, X_2= paunch girth, X_3= body length and X_4= height at wither

Table 4.10. Prediction equations and coefficient of determination (adjusted R^2) for predicting body weight from body measurements at three months of age

Groups	Equation	Adjusted R^2
Female	$Y= -8.970+ 0.386X_1$	0.676
	$Y= -9.997+ 0.328X_1+ 0.086X_3$	0.694
Male	$Y= -10.819+ 0.422X_1$	0.771
	$Y= -11.944+ 0.384X_1+ 0.063X_4$	0.776
	$Y= -11.768+ 0.310X_1+ 0.062X_4+ 0.066X_2$	0.781
	$Y= -11.925+0.325X_1+ 0.096X_4+ 0.074X_2+ -0.057X_3$	0.786
Single	$Y= -8.577+ 0.380X_1$	0.653
	$Y= -9.626+ 0.347X_1+ 0.056X_4$	0.660
Twin	$Y= -10.093+ 0.404X_1$	0.748
	$Y= -12.168+0.338X_1+0.112X_4$	0.767
	$Y=-11.808+0.262X_1+0.109X_4+0.066X_2$	0.773
Triplet	$Y= -11.819+0.448X_1$	0.733
Tellichery	$Y= -6.649+0.336X_1$	0.648
	$Y= -8.216+0.274X_1+0.097X_4$	0.666
	$Y=8.526+0.220X_1+0.097X_4+0.055X_2$	0.670
Badagara	$Y= -7.247+0.346X_1$	0.597
	$Y= -8.517+0.299X_1+0.079X_3$	0.613
Tanur	$Y= -4.814+0.288X_1$	0.519
Pooled	$Y=-9.630+ 0.399X_1$	0.703
	$Y= -10.941+ 0.353X_1+ 0.075X_4$	0.713
	$Y= -10.920+ 0.309X_1+ 0.075X_4+ 0.040X_2$	0.715

Y= body weight, X_1=chest girth, X_2= paunch girth, X_3= body length and X_4= height at wither

Table 4.11. Prediction equations and coefficient of determination (adjusted R^2) for predicting body weight from body measurements at six months of age

Groups	Equation	Adjusted R^2
Female	$Y= -8.829+ 0.438X_1$	0.639
	$Y= -12.670+ 0.344X_1+ 0.166X_4$	0.669
Male	$Y= -6.542+ 0.399X_1$	0.567
	$Y= -10.662+0 .285X_1+ 0.189X_4$	0.603
Single	$Y= -9.572+ 0.450X_1$	0.583
	$Y= -13.031+0.349X_1+ 0.166X_4$	0.612
Twin	$Y= -4.715+0.368X_1$	0.588
	$Y= -8.436+ 0.280X_1+ 0.156X_4$	0.632
Triplet	$Y= -12.985+ 0.512X_1$	0.734
Tellichery	$Y= -13.480+0.510 X_1$	0.630
	$Y= -14.230 +0.348 X_1+0.190 X_3$	0.672
Badagara	$Y= -8.103+ 0.420 X_1$	0.496
	$Y= -10.583 +0 .298X_1+ 0.172 X_4$	0.527
Tanur	$Y= -9.896+0.476 X_1$	0.509
	$Y= -15.363+ 0.292 X_1+0.281 X_4$	0.579
Pooled	$Y= -7.916+ 0.423X_1$	0.603
	$Y= -11.624+ 0.328X_1+ 0.164X_4$	0.634

Y= body weight, X_1=chest girth, X_2= paunch girth, X_3= body length and X_4= height at wither

Table 4.12. Predicted weight ±Standard error and predicted bias based on the best predicted equation sex wise, type of birth wise, centre wise and pooled data for Malabari goats at below one, three and six months of age

Age		Female	Male	Single	Twin	Triplet	Tellichery	Badagara	Tanur	Pooled
Below one month	Mean ±SE	2.36±0.03	2.39±0.02	2.36±0.03	2.42±0.03	2.29±0.05	2.37±0.02	2.32±0.058	2.39±0.04	2.374±0.02
	Predicted bias	0.0125^{ns}	0.0120^{ns}	0.0099^{ns}	1.1020^{ns}	0.0011^{ns}	1.3634^{ns}	1.0348^{ns}	0.8189^{ns}	0.4615^{ns}
Three months	Mean ±SE	9.50±0.11	9.61±0.15	9.91±0.09	9.05±0.16	8.96±0.42	9.53±0.09	9.90±0.15	7.39±0.14	9.519±0.08
	Predicted bias	0.2603^{ns}	0.0745^{ns}	0.1732^{ns}	0.1633^{ns}	0.0216^{ns}	0.2294^{ns}	0.0839^{ns}	0.2554^{ns}	0.4531^{ns}
Six months	Mean ±SE	16.07±0.17	16.16±0.21	16.597±0.16	15.32±0.19	14.55±0.65	16.05±0.18	16.70±0.22	14.66±0.20	16.15±0.13
	Predicted bias	0.0768^{ns}	0.0345^{ns}	0.0928^{ns}	0.0743^{ns}	0.0351^{ns}	0.3745^{ns}	0.0068^{ns}	0.0738^{ns}	0.0447^{ns}

^{s} – nonsignificant

Table 4.13. Cost/head/day for rearing kids up to six months of age

Sl.No.	Category	Feed items(daily ration)			Cost of labour	Cost/head/day (Rs)
		Concentrate feed(g)	Fodder(g)	Milk(g)		
1	Kids(0-3)	77.94	208.33	587	1.9756	11.25
2	3-6	258.33	791.67		1.9756	4.62

Table 4.14. Relative economic value of body weight and body measurements at below one, three and six months of age as well as peak yield

Sl.No	Age	Trait	Cost/unit (Rs)	Relative economic value
1	Below one month	Body weight	72.87	0.7978
2		Chest girth	19.76	0.2163
3		Body length	17.06	0.1868
4		Height at wither	18.41	0.2015
5	Three months	Body weight	119.84	1.3100
6		Chest girth	23.32	0.2553
7		Body length	21.16	0.2316
8		Height at wither	23.82	0.2608
9	Six months	Body weight	91.35	1.0000
10		Chest girth	35.46	0.3882
11		Body length	31.20	0.3415
12		Height at wither	35.56	0.3893
13		Peak yield	14.13	0.1547

Table 4.15. Selection indices for the males with their correlation coefficient between index and aggregate genetic worth (r_{IH}), aggregate economic genetic gain and relative efficiencies

Sl.No	Selection Indices	r_{IH}	Aggregate economic genetic gain	Relative efficiency (%)
1	$I=0.2223X_1+ 0.0845X_2$	0.4696	1.3817	21.73
2	$I=0.1371X_1+ 0.1084X_2+ 0.1641X_3$	0.5022	1.9684	30.96
3	$I=-0.0309 X_1+ 0.1654X_2+ 0.2802X_3 - 0.0982X_4$	0.5388	2.2167	34.87
4	$I=-0.2093X_1+ 0.2350X_2+ 0.3772X_3 - 0.1753X_4+ 0.2572X_5$	0.5656	2.9329	46.13
5	$I=-0.3832X_1+ 0.2794X_2+ 0.4967X_3 - 0.1345X_4+ 0.4747X_5 -0.2242 X_6$	0.5902	3.2308	50.82
6	$I=-0.4994X_1+ 0.3844 X_2+ 0.6495X_3 - 0.2293X_4+ 0.4674X_5 -0.0134 X_6 - 0.4058X_7$	0.6225	3.5716	56.18
7	$I=-0.5158X_1+ 0.4492X_2+ 0.6872X_3 - 0.0413X_4+ 0.4431X_5+ 0.1745X_6 - 0.2885 X_7 -0.4371X_8$	0.6814	4.0369	63.50
8	$I=-0.8022 X_1 +0.702X_2 + 0.5497X_3 - 0.0910X_4 + 0.1789X_5 + 0.1294X_6 - 0.3661X_7 -0.4466X_8 + 01.5883X_9$	0.7403	4.7877	75.31
9	$I=-0.8980X_1 + 0.8601X_2 + 0.5448X_3 - 0.1878X_4 + 0.3428X_5 + 0.0937X_6 - 0.4465X_7 -0.5128 X_8 +01.5736X_9 + 0.0552X_{10}$	0.7597	5.4360	85.51
10	$I=-0.7699X_1 +0.8703X_2 + 0.5685X_3 - 0.1853X_4 + 0.2925X_5 + 0.0465X_6 - 0.3422X_7 -0.5636X_8 + 01.7485X_9 + 0.1282 X_{10} -0.2123X_{11}$	0.7690	5.7460	90.38
11	$I=-0.9764X_1+ 0.9586X_2 + 0.5438X_3 - 0.1596 X_4+ 0.1256X_5 + 0.1313X_6 - 0.4968 X_7 -0.6303X_8 + 02.5539 X_9+ 0.2888 X_{10} +0.2339X_{11} -0.6850X_{12}$	0.8267	6.3573	100

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I= inde

Table 4.16. The genetic gain expected in the economic characters with different selection indices for males

Indices	X_1(kg)	X_2(cm)	X_3(cm)	X_4(cm)	X_5(kg)	X_6(cm)	X_7(cm)	X_8(cm)	X_9(kg)	X_{10}(cm)	X_{11}(cm)	X_{12}(cm)
I_1	0.222	0.354										
I_2	0.213	0.434	0.336									
I_3	0.230	0.434	0.323	0.154								
I_4	0.212	0.419	0.318	0.170	0.158							
I_5	0.205	0.415	0.303	0.150	0.194	0.202						
I_6	0.181	0.472	0.327	0.232	0.211	0.222	0.098					
I_7	0.224	0.496	0.350	0.183	0.215	0.219	0.147	0.254				
I_8	0.305	0.553	0.380	0.109	0.239	0.146	0.089	0.172	0.160			
I_9	0.318	0.530	0.367	0.056	0.257	0.115	0.073	0.120	0.175	0.816		
I_{10}	0.339	0.539	0.375	0.040	0.245	0.093	0.065	0.102	0.182	0.838	0.378	
I_{11}	0.364	0.569	0.417	0.044	0.238	0.128	0.135	0.122	0.177	0.796	0.416	0.469

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}=body length at below one month and I_1 to I_{11} – Selection indices

Table 4.17. Selection indices for the females with their correlation coefficient between index and aggregate genetic worth (r_{IH}), aggregate economic genetic gain and relative efficiencies

Sl No	Selection Indices	r_{IH}	Aggregate economic genetic gain	Relative efficiency (%)
1	$I= 0.0619X_1 + 0.060X_2$	0.3393	0.5884	9.10
2	$I= 0.1074X_1 + 0.1083X_2 -0.0614X_3$	0.3425	0.7720	11.94
3	$I= 0.3371X_1 -0.1179X_2 -0.3905 X_3+ 0.6357X_4$	0.6064	1.9399	30.0
4	$I= 0.4458 X_1 -0.2578X_2 -0.3259X_3+ 0.5819 X_4 +0.5814X_5$	0.5402	2.5546	39.50
5	$I= 0.4164X_1 -0.2087X_2 -0.4011X_3+ 0.7363X_4 + 0.6010X_5 -0.1120X_6$	0.5475	2.8146	43.53
6	$I= 0.3743X_1 -0.1247X_2 -0.3396X_3 + 0.9104X_4 + 0.4755X_5 + 0.0669X_6 -0.4568X_7$	0.6225	3.3239	51.41
7	$I= 0.3486X_1 -0.0938X_2 -0.4437X_3 + 01.1113X_4 + 0.4093X_5 + 0.0888X_6 -0.3962X_7 -0.1726X_8$	0.6327	3.5886	55.50
8	$I= 0.3628X_1 +0.0656X_2 -0.6294X_3 + 01.1567X_4+ 0.4820X_5 -0.0568X_6 -0.4283X_7 -0.2281X_8 + 02.7112X_9$	0.7826	4.8105	74.40
9	$I= 0.6861X_1 -0.0259X_2 -0.2820X_3 +0.8974X_4 + 0.7931 X_5 -0.3111X_6 -0.5247 X_7 - 0.0132X8 + 03.8382X_9 -0.5487X_{10}$	0.9128	5.4865	84.85
10	$I= 0.7755X_1 -0.2019 X_2 -0.306 X_3+ 0.9778X_4 + 01.3755X_5 -0.4326X_6 -0.5490X_7 + 0.1790X_8+ 04.3841X_9 -0.5411X_{10} -0.2161X_{11}$	0.9184	5.8801	90.94
11	$I=0.6393 X_1 -0.1980X_2 -0.0709 X_3+ 0.6245X_4 + 01.7306X_5 -0.2740X_6 -0.5038X_7 - 0.0417X_8 + 05.0545X_9 -0.6293X_{10} + 0.3482X_{11} -0.6915X_{12}$	0.9881	6.4658	100

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I= Index

Table 4.18. The genetic gain expected in the economic characters with different selection indices for females

Indices	X_1(kg)	X_2(cm)	X_3(cm)	X_4(cm)	X_5(kg)	X_6(cm)	X_7(cm)	X_8(cm)	X_9(kg)	X_{10}(cm)	X_{11}(cm)	X_{12}(cm)
I_1	0.236	0.909										
I_2	0.219	1.035	0.390									
I_3	0.260	1.926	0.978	1.613								
I_4	0.507	1.371	1.034	0.982	0.593							
I_5	0.507	1.467	1.042	1.079	0.544	0.985						
I_6	0.582	1.607	1.135	1.215	0.580	1.028	0.913					
I_7	0.513	1.732	1.137	1.360	0.492	1.172	1.077	1.176				
I_8	0.815	2.158	1.299	1.584	0.768	1.278	1.029	1.257	0.274			
I_9	0.748	2.390	1.469	1.782	0.913	1.696	1.348	1.490	0.279	0.380		
I_{10}	0.790	2.351	1.488	1.778	0.928	1.613	1.279	1.461	0.291	0.571	1.667	
I_{11}	0.826	2.377	1.736	1.971	0.968	1.672	1.351	1.558	0.308	0.739	1.767	1.061

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I_1 to I_{11} – Selection indices

Table 4.19. Selection indices for the singles with their correlation coefficient between index and aggregate genetic worth (r_{IH}), aggregate economic genetic gain and relative efficiencies

Sl No	Selection Indices	r_{IH}	Aggregate economic genetic gain	Relative efficiency (%)
1	$I=0.2446X_1+0.0811X_2$	0.4848	1.4378	10.76
2	$I=0.4407X_1-0.1935X_2+0.2828X_3$	0.6313	2.4280	18.17
3	$I=0.3449X_1-0.3053X_2+0.3957X_3+0.1798X_4$	0.6442	3.5668	26.69
4	$I=0.7713X_1-0.9544X_2+0.9966X_3+0.2483X_4-2.044X_5$	1.0725	5.7021	42.67
5	$I=01.0341X_1-01.4585X_2+01.3034X_3+0.3624X_4-03.5926X_5+0.7171X_6$	1.2584	5.6629	42.38
6	$I=01.1140X_1+-01.8745X_2+02.0739X_3+0.7684X_4-03.1281X_5+0.9396X_6-0.7024X_7$	1.3772	7.0845	53.01
7	$I=0.9514X_1-02.4150X_2+02.6255X_3+01.5701X_4-02.6619X_5+01.2640X_6-0.8362X_7-0.7021X_8$	1.4781	8.4310	63.09
8	$I=01.8780X_1-03.2956X_2+02.9854X_3+01.3581X_4-04.4882X_5+02.7807X_6-0.9907X_7-0.3237X_8-02.1482X_9$	1.8253	8.7683	65.61
9	$I=02.3439X_1-03.7496X_2+03.1434X_3+01.3169X_4-04.3959X_5+03.4108X_6-01.4157X_7-0.1472X_8-03.8451X_9+0.2955X_{10}$	1.7892	9.8582	73.77
10	$I=02.440X_1\ -04.3426X_2\ 03.5799X_3\ 01.0883X_4\ -05.0457X_5\ 05.0820X_6\ -01.9303X7\ 0.4575X_8\ -07.5351X_9\ 0.1058X_{10}\ 01.1233X_{11}$	1.7404	10.4993	78.57
11	$I=-0.5923X_1-05.5593X_2+04.0386X_3+02.7690X_4+03.6035X_5+09.9151X_6-06.4886X_7-03.2629X_8-25.8698X_9+0.3289X_{10}-0.0574X_{11}+08.1193X_{12}$	1.9998	13.3635	100

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month , X_{12}= body length at below one month and I= index

Table 4.20. The genetic gain expected in the economic characters with different selection indices for singles

Indices	X_1(kg)	X_2(cm)	X_3(cm)	X_4(cm)	X_5(kg)	X_6(cm)	X_7(cm)	X_8(cm)	X_9(kg)	X_{10}(cm)	X_{11}(cm)	X_{12}(cm)
I_1	1.055	0.985										
I_2	1.473	-0.191	2.644									
I_3	1.568	-0.139	2.682	2.954								
I_4	1.801	0.814	3.209	3.755	0.804							
I_5	1.890	0.765	2.883	3.764	0.902	-0.442						
I_6	1.946	0.594	2.920	3.834	0.982	-0.333	4.834					
I_7	2.125	0.841	2.767	4.185	0.921	-0.244	4.729	4.724				
I_8	2.198	0.859	2.681	4.266	0.941	-0.113	4.727	4.778	0.241			
I_9	2.122	0.455	2.437	3.958	1.052	0.247	4.637	4.781	0.494	5.121		
I_{10}	2.148	0.368	2.375	3.946	1.069	0.298	4.615	4.788	0.551	5.381	2.702	
I_{11}	2.938	1.242	2.901	5.532	0.971	-0.108	5.253	5.366	0.309	5.303	2.981	5.747

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I_1 to I_{11} – Selection indices

Table 4.21. Selection indices for the twins with their correlation coefficient between index and aggregate genetic worth (r_{IH}), aggregate economic genetic gain and relative efficiencies

Sl No	Selection Indices	r_{IH}	Aggregate economic genetic gain	Relative efficiency (%)
1	$I=0.1465X_1+ 0.0237X_2$	0.3631	0.4753	9.23
2	$I=0.0661X_1+ -0.0532X_2+ 0.1964X_3$	0.4910	1.2138	23.59
3	$I=0.0873X_1 -0.0102X_2+ 0.1296X_3+ 0.2081X_4$	0.5245	1.6719	32.49
4	$I=0.0654 X_1 -0.1231X_2+ 0.1596 X_3+ 0.2595X_4+ 0.3487X_5$	0.5444	2.5547	49.65
5	$I=0.1165 X_1+ -0.1052X_2+ 0.1988X_3+ 0.3356X_4+ 0.3937X_5 -0.0779 X_6$	0.5504	2.9101	56.56
6	$I=0.3095X_1 -0.0596X_2+ 0.1302X_3+ 0.4631 X_4+ 0.0557X_5 -0.1781X_6+ 0.2596X_7$	0.5716	3.3632	65.36
7	$I=0.4958X_1 -0.2823X_2+ 0.0317X_3+ 0.4736X_4+ 0.3166X_5-0.0654X_6+ 0.3596X_7+ -0.4591X_8$	0.6059	3.6686	71.30
8	$I=0.4582X_1 -0.2413X_2 +0.0162X_3+ 0.3884X_4 -0.3574X_5 -0.1664X_6+ 0.4838X_7 -0.2568X_8 -06.8960X_9$	0.7588	4.4272	86.04
9	$I= 0.4361X_1 -0.0529X_2\ 0.0658X3 + 0.2531X_4 -0.2659X_5 -0.1631X_6+ 0.4825X_7 -0.3332X8 -06.9924X_9 -0.2121X_{10}$	0.7990	4.5226	87.90
10	$I= 0.1915X_1 -0.1499X_2\ 0.2345X_3+ 0.1727X_4 -0.6438X_5 -0.1020X_6+ 0.4833X_7 -0.3533X_8 -07.1667X_9 -0.3453X_{10} + 0.3056X_{11}$	0.8125	4.9478	96.16
11	$I= 0.1255X_1 -0.0374X_2 +0.2665X_3+ 0.1021X_4 -0.8386X_5 -0.0951X_6+ 0.5411X_7 -0.3308X_8 -06.7760X_9 -0.4732X_{10} +0.3311X_{11}+ 0.3194 X_{12}$	0.8205	5.1453	100

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I= Index

Table 4.22. The genetic gain expected in the economic characters with different selection indices for twins

Indices	X_1(kg)	X_2(cm)	X_3(cm)	X_4(cm)	X_5(kg)	X_6(cm)	X_7(cm)	X_8(cm)	X_9(kg)	X_{10}(cm)	X_{11}(cm)	X_{12}(cm)
I_1	0.390	0.219										
I_2	0.585	0.390	1.226									
I_3	0.657	0.386	1.394	0.942								
I_4	0.675	0.351	1.402	1.003	0.653							
I_5	0.652	0.363	1.414	1.020	0.662	1.376						
I_6	0.703	0.409	1.502	1.035	0.642	1.550	1.252					
I_7	0.720	0.470	1.622	1.093	0.672	1.596	1.290	0.590				
I_8	0.917	0.575	2.003	1.332	0.787	2.010	1.695	0.749	-0.134			
I_9	0.971	0.507	1.978	1.370	0.828	2.102	1.776	0.910	-0.137	-0.316		
I_{10}	0.991	0.489	2.017	1.443	0.899	2.087	1.748	0.932	-0.144	-0.360	1.489	
I_{11}	1.008	0.431	1.997	1.490	0.950	2.086	1.730	1.006	-0.147	-0.544	1.598	0.720

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I_1 to I_{11} – Selection indices

Table 4.23. Selection indices for the pooled data with their correlation coefficient between index and aggregate genetic worth (r_{IH}), aggregate economic genetic gain and relative efficiencies

Sl No	Indices	r_{IH}	Aggregate economic genetic gain	Relative efficiency (%)
1	$I=0.1907X_1 + 0.1429X_2$	0.5226	1.9653	31.21
2	$I=0.2084X_1 + 0.1085X_2 + 0.1693X_3$	0.5349	2.6297	41.76
3	$I=0.2711X_1 + 0.1449X_2 + 0.2214X_3 - 0.0140X_4$	0.5339	3.3520	53.23
4	$I=0.3198X_1 + 0.2652X_2 + 0.2674X_3 - 0.1114X_4 - 0.5116X_5$	0.5960	3.7389	59.37
5	$I=0.2373X_1 + 0.3272X_2 + 0.2880X_3 - 0.1274X_4 - 0.2777X_5 - 0.1465X_6$	0.6221	3.8694	61.44
6	$I=0.2247X_1 + 0.2905X_2 + 0.4314X_3 - 0.1410X_4 - 0.2879X_5 - 0.057X_6 - 0.1906X_7$	0.6417	4.0177	63.80
7	$I=0.2451X_1 + 0.3038X_2 + 0.4701X_3 - 0.1978X_4 - 0.3551X_5 - 0.0286X_6 - 0.2295X_7 + 0.1374X_8$	0.6475	4.1416	65.76
8	$I=0.160X_1 + 0.3958X_2 + 0.3793X_3 - 0.1757X_4 - 0.4961X_5 - 0.0931X_6 - 0.1743X_7 + 0.014 X_8 + 01.4926X_9$	0.7082	4.8445	76.92
9	$I=0.0875X_1 + 0.4509X_2 + 0.3696X_3 - 0.1769 X_4 - 0.5155X_5 - 0.0936X_6 - 0.2011X_7 + 0.073X_8 + 01.0543X_9 + 0.2082X_{10}$	0.7123	5.3312	84.65
10	$I=0.1113X_1 + 0.4997X_2 + 0.4320X_3 - 0.3085X_4 - 0.5862X5 - 0.0338X6 - 0.2861X_7 - 0.027 X8 + 0.8867X9 + 0.0807X_{10} + 0.3244X_{11}$	0.7257	5.9443	94.39
11	$I= 0.1222X_1 + 0.4857X_2 + 0.4635X_3 - 0.3158X_4 - 0.5832X_5 - 0.0308X_6 - 0.2979 X_7 - 0.038X_8 + 01.2742X_9 + 0.106X_{10} + 0.5035X_{11} - 0.2857X_{12}$	0.7324	6.2974	100

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I= Index

Table 4.24. The genetic gain expected in the economic characters with different selection indices for pooled data

Indices	X_1(kg)	X_2(cm)	X_3(cm)	X_4(cm)	X_5(kg)	X_6(cm)	X_7(cm)	X_8(cm)	X_9(kg)	X_{10}(cm)	X_{11}(cm)	X_{12}(cm)
I_1	1.041	2.380										
I_2	1.118	2.294	1.574									
I_3	1.122	2.304	1.579	2.110								
I_4	1.212	2.465	1.650	2.402	0.082							
I_5	1.247	2.537	1.639	2.441	0.103	0.119						
I_6	1.271	2.557	1.645	2.417	0.143	0.092	0.297					
I_7	1.258	2.474	1.669	2.367	0.166	0.129	0.344	0.537				
I_8	1.426	2.655	1.828	2.429	0.215	0.259	0.479	0.453	0.336			
I_9	1.408	2.635	1.836	2.462	0.218	0.305	0.536	0.560	0.371	1.920		
I_{10}	1.446	2.706	1.933	2.458	0.268	0.371	0.592	0.673	0.378	1.809	2.017	
I_{11}	1.490	2.817	2.029	2.635	0.227	0.374	0.662	0.693	0.354	1.673	2.026	1.318

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month and I_1 to I_{11} – Selection indices

Table 4.25. A comparison of indices having highest aggregate economic genetic gain and expected genetic gain for body weight at six months of age correlation coefficient between index and aggregate genetic worth (r_{IH}) for males, females, singles, twins and pooled data

Group	Index No	Aggregate economic genetic gain	Expected genetic gain for body weight at six months of age (kg)	r_{IH}	No. of sires	Average number of progeny per sire
Males	I_{11}	6.3573	0.364	0.8267	5	6.6
Females	I_{11}	6.4658	0.826	0.9881	5	6.6
Singles	I_{11}	13.3635	2.938	1.9998	4	3.75
Twins	I_{11}	5.1453	1.008	0.8205	4	7.75
Pooled	I_{11}	6.2974	1.490	0.7324	9	9.78

I_{11} = Eleventh index

Table 4.26. Restricted selection indices with correlation coefficient between index and aggregate genetic worth (r_{IH})

Category	Restricted Selection indices	r_{IH}
Male	I_m= -0.9696 X_1+ 0.9266X_2 +0.5446X_3-0.1419X_4+0.1093 X_5+0.1403 X_6+-0.4910 X_7-0.6138X_8+2.5505 X_9+0.2765 X_{10} +0.2441 X_{11}-0.6889 X_{12}	0.2577
Female	I_f= -0.2196X_1 -0.1628 X_2+ 0.3810 X_3 -0.1371 X_4 +0.3032 X_5 -0.0432 X_6 -0.0839 X_7 -0.2405 X_8 +3.3348 X_9 -0.4555 X_{10} + 0.2595 X_{11} -0.2471X_{12}	0.5711
Single	I_s= -9.7862X_1 + 2.4307X_2 +1.7866X_3 +5.4040X_4 + 16.0426 X_5 - 0.1177X_6 - 4.4774X_7 - 11.2945 X_8 -13.0842X_9 + 3.8715X_{10} - 12.1555X_{11}+ 10.4434X_{12}	-0.1263
Twin	I_t= -0.1811X_1 -0.0687X_2 -0.0066 X_3 -0.0230 X_4 -0.2363 X_5 -0.0422 X_6+0.0068 X_7 -0.0876 X8 -5.2322 X_9 -0.0728 X_{10} +0.0249X_{11}+0.0121X_{12}	0.3680
Pooled	I_p= -0.0456X_1+0.1567X_2+0.0330X_3+0.1447X_4 -0.4365X_5-0.0672X_6-0.1398 X_7+0.0247X_8+1.4743 X_9-0.1883 X_{10}+0.6437 X_{11}-0.7246 X_{12}	0.4782

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six months, X_5= body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three months, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month and X_{12}= body length at below one month , I_m= restricted selection index for males, I_f = restricted selection index for females, I_s = restricted selection index for singles, I_t = restricted selection index for twins, I_p = restricted selection index for pooled data

Table 4.27. Genetic gain for individual characters by the application of restricted selection indices

Indices	X_1(kg)	X_2(cm)	X_3(cm)	X_4(cm)	X_5(kg)	X_6(cm)	X_7(cm)	X_8(cm)	X_9(kg)	X_{10}(cm)	X_{11}(cm)	X_{12}(cm)
I_m	0.180	0.286	0.210	0.026	0.118	0.067	0.069	0.066	0.087	0.392	0.206	0.231
I_f	0.246	0.727	0.534	0.545	0.335	0.509	0.456	0.471	0.000	0.081	0.517	0.352
I_s	/	/	/	/	/	/	/	/	/	/	/	/
I_t	0.219	0.124	0.441	0.283	0.197	0.496	0.430	0.261	0.000	0.008	0.330	0.090
I_p	0.630	1.314	0.888	1.377	-0.034	0.017	0.259	0.127	0.000	-0.008	0.519	-0.088

X_1=body weight at six months, X_2= chest girth at six months, X_3= height at wither at six months, X_4= body length at six mo body weight at three months, X_6=chest girth at three months, X_7= height at wither at three months, X_8= body length at three month, X_9= body weight at below one month, X_{10}= chest girth at below one month, X_{11}= Height at wither at below one month, X_{12}= body length at below one month, I_m= restricted selection index for males, I_f = restricted selection index for females, I_s = restricted selection index for singles, I_t = restricted selection index for twins and I_p = restricted selection index for pooled data.

/ - cannot estimable

DISCUSSION

5. DISCUSSION

Multi-trait selection is gaining importance in animal breeding, as the improvement of overall genetic worth of the animal is necessary for a profitable enterprise. Selection index is considered to be the best method of multi-trait selection since the economic values, as well as genetic and phenotypic variance and covariance of the traits under selection are considered. The work on index selection in goats of Kerala is scanty and totally lacking under field conditions. This work focuses on different aspects of formulation of selection indices and its efficiency in Malabari goats from the data recorded on farmers' flock. The topic is discussed under the following heads:

5.1 Body weights
5.2 Body measurements
5.3 Milk production
5.4 Prolificacy
5.5 Heritability of body weight and body measurements
5.6 Correlations among body weight and body measurements
5.7 Genetic parameters of milk production
5.8 Prediction of body weight from body measurements
5.9 Selection indices

5.1 BODY WEIGHTS

5.1.1 Body Weights up to Six Months of Age

The overall mean body weight recorded for Malabari kids were 3.12±0.11, 8.28±0.18 and 15.99±0.33 kg respectively for below one, three and six months of age. The mean body weights recorded at different age groups were higher than that of Menon (1994) and Raghavan and Anilkumar (2000) under farm conditions.

5.1.2 Factors Affecting Body Weights

Effect of different non-genetic factors affecting body weight at different ages *viz.*, centre where animals were reared, sex of the animal, type of birth, year and season of birth were estimated.

5.1.2.1 Effect of Centre

Centre had significant effect on body weight in all the three age groups. The significant effect of different centres is due to the regional differences as they are located in three different districts of Kerala. So there may be differences in the herd management and resources. This result was comparable with the result obtained by Bindu (2006) in Malabari goats and Sghaier *et al.* (2007) in indigenous kids of Tunisian arid region.

5.1.2.2 Effect of Sex

Sex of the kid had significant influence on body weight at below one, three and six months of age. Males were heavier than females. Raghavan (1980) in Malabari cross breds, Mukundan *et al.* (1983) in Malabari and its Saanen half-breds, Salah *et al.* (1989) in Aardi kids, Saxena *et al.* (1990) in Jamunapari kids, Tyagi *et al.* (1992) in Jakhrana goats, Menon (1994) in Malabari goats, Singh *et al.* (2000a) in Beetal half bred kids, Zhou *et al.* (2003) in inner Mongolia Cashmere goats, Kosum *et al.* (2004) in Saanen, Bornova and Saanen×Kilis goats, Liu *et al.* (2005) in Angora goats, and Thiruvenkadan *et al.* (2008) in Tellicheri kids also reported significant effect of sex on body weight at different ages. Reason for the higher growth rate in males than females may be due to the early secretion of sex hormones by gonads of male kids. The anabolic effect of androgens in male kids is attributed to be the reason for the faster growth rate during post-natal life. Non-significant effect of sex was reported by Raghavan (1980) in the birth weight for Malabari and body weights at one and four months of age for Alpine× Malabari and Malabari, by Khan and Sahni (1983) in Jamunapari goats for body weights at first and second month, by Sharma *et al.* (1984) in Assam local × Beetal kids and by Singh *et al.* (2000a) in Beetal halfbred kids.

5.1.2.3 Effect of Type of Birth

Type of birth had significant effect up to three months of age but not later. This indicated that the type of birth exerted no influence on body weight at later ages. Twin births bring double the profit compared to singles, and triplets three times the profit. Similar results were also observed by Raghavan (1980) in Malabari and its crossbreds, Khan and Sahni (1983) and Saxena *et al.* (1990) in Jamunapari goats, Salah *et al.* (1989) in Aaradi goats, Singh *et al.* (2000a) in Beetal halfbred kids, Zhou *et al.* (2003) in inner Mongolia Cashmere goats, Kosum *et al.* (2004) in Saanen, Bornova and Saanen×Kilis goats, Liu *et al.* (2005) in Angora goats and Thiruvenkadan *et al.* (2008) in Tellicheri kids. Singles were significantly heavier than twins and triplets. This might be due to the availability of more nutrients to the single kids than those born in multiple births during pre and early post-natal life.

5.1.2.4 Effect of Year of Birth

Significant effect of year of birth was observed on body weight in all age groups except in the case of body weight at below one month of age. This effect of year of birth on weight was also reported by Khan and Sahni (1983) in Jamunapari goats, Kosum *et al.* (2004) in Saanen, Bornova and Saanen × Kilis goats, Liu *et al.* (2005) in Angora goats, Sghaier *et al.* (2007) in indigenous kids under Pastoral mode in Tunisisan arid region and McManus *et al.* (2008) in Saanen, Alpine and Toggenburg goats. This difference might be due to variations in the climate, nutrition and management prevailed in those years.

5.1.2.5 Effect of Season

There was a significant effect of season of birth on body weight except at six months of age. Kids born in summer were heavier than those born in other seasons. This might be attributed to favourable climatic conditions and abundant availability of the tree fodder during the gestation period of does conceived, in North-east monsoon. Seasonal effects on weight are a common feature of traditionally managed flocks. Studies by Khan and Sahni (1983) in Jamunapari goats, Mavrogenis (1984a) in Damascus goat, Malik *et al.* (1986) in Beetal and Black Bengal kids and their crosses, Tyagi *et al.* (1992) in Jakharna goats, and Singh *et al.* (2000a) in Beetal halfbred kids revealed a significant effect of season on body weight at different ages. But Raghavan (1980) and Menon (1994) working on Malabari and its crossbreds with Saanen and Alpine, Salah *et al.* (1989) working on Aaradi goats, and Thiruvenkadan *et al.* (2008) studying Tellicheri kids reported non-significant effect of season of birth on body weight.

The results on body weight up to six months of age and factors affecting it have shown that the growth rate of Malabari goats under field conditions was higher than that under farm conditions. This might be due to the individual care and management given in farmers' flocks. Though sex exerted a significant influence on this trait, type of birth was a significant source of variation only at earlier ages up to three months. Seasonal and year differences noticed might probably be due to variation in climatic conditions and feed availability in different periods.

5.2 BODY MEASUREMENTS UP TO SIX MONTHS OF AGE

5.2.1 Body Measurements up to Six Months of Age

The overall mean of chest girth at below one month, three and six months of age were 35.47±0.45, 46.12±0.46 and 56.67±0.58 cm respectively. The overall mean of body lengths were recorded as 32.49±0.50, 42.30±0.46 and 50.51±00.63 cm in the same order whereas the same for height at withers were 35.67±0.46, 45.17±0.45 and 55.32±0.58 cm. The chest girth was almost similar to the earlier reports but the body length was slightly higher (Anon., 2007).

5.2.2 Factors Affecting Body Measurements

As in the case of body weight, different non-genetic factors affected body measurements at different ages. Least-squares analysis was carried out to study the influence of these factors on body measurements.

5.2.2.1 Effect of Centre

Place of birth and rearing had significant effect on body measurements at below one, three and six months of age. Badagara born animals had higher body measurements in all the age groups followed by Tellichery and Tanur born kids. This may be attributed to the regional differences.

5.2.2.2 Effect of Sex

Males had a higher estimate for all body measurements recorded at below one, three and six months of age. Similar results were also observed by Tomar *et al.* (2001) in Sirohi goats. But a non-significant effect of sex was reported by Karna *et* *al.* (2001) in Chegu kids and Singh (2002) in Black Bengal and its halfbreds with Jamunapari and Beetal. Since body weight had positive correlation with measurements, sex influenced the conformation traits also.

5.2.2.3 Effect of Type of Birth

Type of birth had significant effect on body measurements at below one and three months of age. But the effect of type of birth was found to be non-significant in the body measurements at six months of age except for body length. Similar trend for body measurements were also reported by Tomar *et al.* (2001) in Sirohi goats, Das *et al.* (2002) in Assam local and crossbred goats, Singh (2002) in Black Bengal and its halfbreds with Jamunapari and Beetal and Liu *et al.* (2005) in Angora goats.

5.2.2.4 Effect of Year of Birth

Year of birth had a significant effect on body measurements at all age groups *viz.*, below one, three and six months of age. These findings were in agreement with those reported by Tomar *et al.* (2001) in Sirohi goats, Karna *et al.* (2001) in Chegu goats and Liu *et al.* (2005) in Angora goats. Kids born in the year 2005 had a higher mean for all the three measurements at below one, three and six months of age. Because birth year is a complex variable incorporating conditions of climate, feeding and management, the significant effect of year of birth is justified.

5.2.2.5 Effect of Season

Season of birth had significant effect on body measurements at below one, three and six months of age. Summer born kids had higher body measurements compared to the winter and rainy season born kids in all the age groups studied. This might be due to changes in feeding habits at this time of year, but also probably was influenced by environmental temperatures and relative air humidity. Similar trend was also observed by Karna *et al.* (2001) in Chegu kids and Das *et al.* (2002) in Assam local and crossbred goats and Singh (2002) in Black Bengal and its halfbreds with Beetal and Jamunapari.

Body measurements were also affected similarly as body weight, and different factors that caused variation in body weight also affected body measurements.

5.3 MILK PRODUCTION

Under field conditions, it is difficult to record daily yield in goats. The practical solution to this is recording of peak yield of animals, which gives an indication of total milk production in goats. Fernández *et al.* (2002) and Singh and Kumar (2007) designed methods for the prediction of total milk yield from peak yield in Murciano-Granadina goats and in cattle respectively.

5.3.1 Peak Yield in Malabari Goats

The mean peak yield in Malabari goats was recorded as 1237.62±75.44 ml. This was higher than the early value reported (Anon., 2007) which was 850.80±62.91ml.

5.3.2 Factors Affecting Milk Production in Malabari Goats

Different non-genetic factors affect peak yield in Malabari goats. Least-squares analysis was conducted to study the effect of different factors *viz.*, centre, season and year of kidding.

5.3.2.1 Effect of Centre

Milk yield was influenced by the effect of centre and Badagara animals yielded more milk (1978.28±113.60 ml) followed by the Tellichery and Tanur animals. The variations in the same breed of animals in milk yield might be due to difference in management systems and feeding. Gokhale *et al.* (1997) working on non-descript and graded Sirohi goats and Cripaldi *et al.* (1999) studying Alpine goats in Lombardy in Italy reported similar variation with region in milk production.

5.3.2.2 Effect of Year of Kidding

Year of birth had significant influence on the peak yield of Malabari goats. The animals kidded in the year 2008 had higher average peak yield than other years. The lower yield in other years might be due to the unfavorable climatic conditions and poor managemental practices in those years. These findings are in agreement with those reported by Mavrogenis (1984b) in Damascus goats, Gokhale *et al.* (1997) in rural goats of Rajasthan and Kumar *et al.* (2004) in Kutchi goats.

5.3.2.3 Effect of Season of Kidding

Peak milk yield was also influenced by season of kidding. The animals kidded in the winter season had highest mean peak yield (1400.40±77.37 ml). This was followed by those kidded in summer season (1204.39±80.98 ml) and rainy season (1108.06±87.69 ml). This could be due to the availability of sufficient nutrients in the form of greens during monsoon (during pregnancy) and winter (lactation period). Similar results were also observed by Cripaldi *et al.* (1999) in Alpine goats in Lombardy in Italy, Singh *et al.* (2000b) in Black Bengal and its halfbreds and Kumar *et al.* (2004) in Kutchi goats.

A high peak yield of 1237.62±75.44 ml reported in this study indicated the milk production potential of this milch breed of goats under field conditions. Centre where the animals were reared, year and season of kidding affected peak yield in this breed of goats.

5.4 PROLIFICACY

The percentage of multiple births (75.71%) was higher compared to singles (24.29%) in the populations studied. The percentage of multiple births was higher in Tanur (79.39%) than in Badagara (74.87%) and Tellichery (74.56%). Similar observations were made by Shanmughasundaram (1957), Raghavan *et al.* (2004), Bindu (2006), Seena (2006) and Joseph (2007) in Malabari goats. Regional differences in prolificacy may be due to free mixing up of Malabari goats with the local population, which is considered to be highly prolific. High prolificacy is considered to be a character of local goat populations.

5.5 HERITABILITY OF BODY WEIGHT AND BODY MEASUREMENTS

Heritability of body weight and body measurements is essential for the formulation of different selection indices incorporating growth. Since the ideal time for selection of Malabari goats under field conditions is six months of age, the traits up to six months of age were considered.

5.5.1 Heritability of Body Weight up to Six Months of Age

A higher heritability estimate was obtained for both below one and six month body weight whereas a very low estimate was obtained for three month body weight.

The heritability estimates for below one month body weight was in agreement with those reported in Malabari goats (Menon, 1994) and in common African and Alpine crossbred goats (Mourad and Anous, 1998). Contrary to this, a lower estimate was reported in other studies like those by Madeli and Patro (1984) in Ganjam goats (0.185), Mavrogenis (1984a) in Damascus goats (0.31), Malik *et al.* (1986) for Beetal and Black Bengal goats (0.21 and 0.23), Schoeman *et al.* (1997) and Zhang *et al.* (2009) in the Boer goat (0.16 and 0.30), Mugambi *et al.* (2007) in Kenya Dual purpose goats (0.13) and Otuma and Osakwe (2008) in Nigeria Sahelian goats (0.41).

The heritability estimate for third month body weight was low (0.023). Similar results with low heritability estimate when compared to birth weight were reported in Malabari goats (Menon, 1994), blended goats at Malaya (Das *et al.*, 1996) and Boer goats (Zhang *et al.*, 2009). The decrease in heritability is probably explained by the fact that animals at later ages experience a variety of environments that may cause differences in both genetic and environmental variances. Lower estimates were also reported for Damascus goats (Mavrogenis, 1984a) and Bengal goats (Malik *et al.*, 1986). Literature values of heritability values of three month body weight were generally higher than the estimate for birth weight. A higher estimate of heritability for three month body weight was reported by Schoeman *et al.* (1997) for Boer goats, Mourad and Anous (1998) in common African and Alpine crossbred goats, Al-Shorepy *et al.* (2002) in Emirati goats and Otuma and Osakwe (2008) for Sahelian goats.

At six months of age, a high heritability estimate was noted in case of body weight. High estimate of heritability for body weight at six months of age was reported in kids of various genetic groups by Singh (2002). Studies by Madeli and Patro (1984) in Ganjam goats, Mourad and Anous (1998) in common African and

Alpine crossbred goats and Bosso *et al.* (2007) in West African Dwarf goat resulted in a moderate estimate of heritability for body weight at six month of age.

High heritability estimate in the body weight at below one and six months of age indicated a comparatively high genetic variability.

5.5.2 Heritability of Body Measurements

The heritability estimates of body measurements at below one month of age were high and ranged from 0.658±0.441 to 0.988±0.515. At three months of age, the heritability estimates were low to moderate. But at six months of age the heritability estimates were high. Karna *et al.* (2001), working in Chegu goats and Zhang *et al.* (2008), studying Boer goats, reported a low estimate of heritability for body measurements at birth and Singh (2002) estimated a moderate to high values of heritability at six months of age for Beetal half breds.

The trend in heritability estimates of body measurements is similar to that of body weight.

5.6 CORRELATIONS AMONG BODY WEIGHT AND BODY MEASUREMENTS

Genetic and phenotypic correlations between body weights at different ages, between body measurements, and between body weight and body measurements were necessary for formulation of selection indices in Malabari goats.

5.6.1 Genetic Correlation

Genetic correlation between body weight and body measurements is due to the similar genes that control these traits and linkage (Falconer and Mackay, 1996).

5.6.1.1 Genetic correlation among Body Weights

The genetic correlation between body weight at below one month and six months was positive, which was in agreement to the reports by Madeli and Patro (1984) in Ganjam goats. This indicated that similar genes influence both these traits. But to the contrary, the genetic correlation between body weight at six and three months of age was negative. The negative genetic correlation between body weight at three and six months of age may be due to low sample size.

5.6.1.2 Genetic Correlation among Body Measurements

Genetic correlations among body measurements within the age group were high. Between different age groups the genetic correlations among body measurements were positive but they had low to high values. Some of the genetic correlations among body measurements were above one due to low sample size. Janssens and Vandepitte (2004) in Belgian Bleu du Maine, Suffolk and Texel sheep and Zhang *et al.* (2008) in Boer goats reported a positive genetic correlation among body measurements.

5.6.1.3 Genetic Correlation between Body Weights and Body Measurements

All estimates of the genetic correlations between body weights and measurements were positive and ranged from a low of 0.060 to a high of 0.985 suggesting that same genes are controlling both body weights and measurements. Some of the genetic correlations arrived at were found to exceed the theoretical limits which may be due to low sample size. The standard error values were a little high in all cases suggesting the same cause. The genetic correlations were always higher than the corresponding phenotypic correlations. Similar results were obtained by Madeli and Patro (1984) in Ganjam goats, Roy *et al.* (1997) in Jamunapari goats, Nahardeka *et al.* (2001) in Assam local goats and their crosses with Beetal and Otuma and Osakwe (2008) in Nigerian Sahelian kids.

5.6.2 Phenotypic Correlations

Phenotypic correlation is the result of joint effect of genotype and environment. Genetic and phenotypic covariance of body weight and body measurements is very essential for preparation of a selection index involving these traits.

5.6.2.1 Phenotypic Correlation among Body Weights

Phenotypic correlation between body weights at below one, three and six months of age were positive and ranged from 0.265±0.104 to 0.412±0.098. Phenotypic correlations values with respect to body weight between age groups of minimal separation was found to be higher than those widely separated. Similar observations were made by Mavrogenis (1984a) in Damascus goats, Roy *et al.* (2003) in Jamunapari goats and Rai *et al.* (2004) in Marwari goats.

5.6.2.2 Phenotypic Correlation among Body Measurements

Phenotypic correlations among body measurements were positive and ranged from low to high values (0.078±0.108 to 0.833±0.060). Similar findings were reported by Deb *et al.* (1998) in Pashmina goats and Janssens and Vandepitte (2004) in Belgian Bleu du Maine, Suffolk and Texel sheep.

5.6.2.3 Phenotypic Correlation between Body Weights and Body Measurements

Positive and highly significant correlations were observed in most of the cases. The correlation coefficients observed in Malabari goats was comparable to the reported values of Singh *et al.* (1979), Prasad *et al.* (1981) in Black Bengal goats, Mukherjee *et al.* (1983) in Grey Bengal goats, Menon (1994) in Malabari and its crosses, Badi *et al.* (2002) in Eritrean goats, Thiruvenkadan (2005) in Kanni Adu kids and Adeyinka and Mohammed (2006) in Nigerian Red Sokoto goats. The high correlation coefficients between body weights and body measurements at all age groups suggest that either of these variables or their combinations could provide a good estimate for predicting live weight of Malabari goats. Since body measurements had high correlation with body weights this may be used as a selection criterion. Bhattacharya *et al.* (1984) in Black Bengal goats and Bose and Basu (1984) in Beetal goats also reported that selection based on body measurements should improve meat production in goats.

The pattern of genetic and phenotypic correlations between the traits studied showed that a higher efficiency can be expected in index selection in Malabari goats.

The possibility of indirect selection at six months of age by selecting for other traits at below one and three months is also possible. Thus the positive genetic and phenotypic correlations existing between the growths traits studied are favorable for increasing body weights and will be advantageous in breeding programmes.

5.7 GENETIC PARAMETERS OF MILK PRODUCTION

Since Malabari goats are dual purpose animals, a selection index involving growth and milk production was separately constructed, for which purpose genetic parameters of milk yield measured as peak yield, *viz.*, heritability and correlations were taken into consideration.

5.7.1 Heritability of Peak Yield

Heritability estimate of peak yield was high and was 0.846 ± 0.561.Similarly a higher estimate for heritability of milk production was reported by Kennedy *et al.* (1982) for Alpines, Saanens, and Toggenburg. But to the contrary, lower estimates of heritability were reported for different breeds for different milk production traits by Mavrogenis (1984b) in Damascus goats, Rai *et al.* (2001a) in Marwari goats, Kumar *et al.* (2004) in Kutchi goats and Morris *et al.* (2006) in Saanen goats.

5.7.2 Genetic correlations

5.7.2.1 Genetic Correlation with Peak Yield and Body Weight

A high genetic correlation was found between peak yield of dam and kid's body weight at three months age. This might be because of the fact that the kid growth during the first three months of life is largely determined by the milk production of their dams. Moderate correlation values were obtained with body weight at six months and below one month. Similar results were observed by Ehoche and Buvanendran (1983) in Red Sokoto goats, Misra *et al.* (1985) in Sirohi goats, Sangre and Pande (2000) in Sahel goats and Jithendrakumar (2003) in Malabari goats.

5.7.2.2 Genetic Correlation with Peak Yield and Body Measurements

Genetic correlation coefficients estimated between body measurements and peak yield were positive and ranged from a low to a high value. Since the body measurements had positive correlation with the body weight, body measurements also have an effect on peak yield, as in the case of body weight.

5.7.3 Phenotypic Correlation

5.7.3.1 Phenotypic Correlation between Peak Yield and Body Weight

Positive phenotypic correlations between peak yield and body weight were seen at below one month (0.10), six months (0.13) but the value was lowest with three month's body weight (0.08). Similar positive correlation were also observed in Ehoche and Buvanendran (1983) in Red Sokoto goats, Misra *et al.* (1985) in Sirohi goats, Sangre and Pande (2000) in Sahel goats and Jithendrakumar (2003) in Malabari goats.

5.7.3.2 Phenotypic Correlation with Peak Yield and Body Measurements

Most of the phenotypic correlations between peak yield and body measurements at below one, three and six months of age were positive except for chest girth (-0.08) and body length (-0.01) at six months age.

Heritability estimate of peak yield was high indicating a high genetic variability existing in the breed for this trait. A high genetic correlation was found between peak yield of dam and kid's body weight at three months of age. Most of the phenotypic correlations between peak yield and body measurements were also positive indicating an increase in body weight and body measurements of kids with increase in peak yield of dam, especially at earlier ages.

5.8 PREDICTION OF BODY WEIGHT FROM BODY MEASUREMENTS

Under field conditions, weighing of animals at regular intervals is not practical. Recording body measurements is comparatively an easier task and if body weight can be predicted from body measurements with reasonable accuracy this will have a lot of applications in selection and improvement of goats. Several authors reported the use of body measurements in prediction of body weight in other breeds *viz.*, Jamunapari and Barbari kids (Das *et al.*, 1990), Jamunapari goats (Sharma and Das, 1995), West African Dwarf goats (Mayaka *et al.*, 1995 and Benyi, 1997), Sahel goats of Nigeria (Mohammed and Amin, 1996), Nguni goats of South Africa (Slippers *et al.*, 2000), Kanni Adu (Thiruvenkadan, 2005) and Red Sokoto goats of Nigeria (Adeyinka and Mohammed, 2006). No work has been conducted in Malabari breed of goats in Kerala under field conditions. Hence the following study has been made to determine the best fitted regression model for prediction of live weight of Malabari goats under field conditions.

The body weight of goats was predicted using body measurements *viz.*, chest girth, paunch girth, body length and height at withers. The coefficient of determination indicated that body measurements succeeded in describing more variation in live weight. The chest girth accounted for maximum variation in live weight in almost all age groups than any other linear measurement. The ease of measurement justifies the use of chest girth as a most suitable weight predictor. The higher association of body weight with chest girth was possibly due to relatively larger contribution of body weight by chest girth (consisting of bones, muscles and viscera). This is in agreement with the findings of Mayaka *et al*. (1995) and Benyi (1997) in West African Dwarf goats; Mohammed and Amin (1996) in Sahel goats of Nigeria; Slippers *et al.* (2000) in Nguni goats of South Africa; Thiruvenkadan (2005) in Kanni Adu and Adenyika and Mohammed (2006) in Nigerian Red Sokoto goats.

The prediction equations obtained suggests that one single body measurement cannot predict body weight of goat accurately. Since highest variation of body weight was accounted to a combination of height at withers, chest girth, body length and paunch girth than individually, multiple regression analysis is more effective. These results are also supported by Bose and Basu (1984) in Beetal goats; Bhattacharya *et al*. (1984) in Black Bengal goats; Sharma and Das (1995) in Jamunapari goats, Bassano *et al.* (2003) in Alpine Ibex and Thiruvenkadan (2005) in Kanni Adu.

In all the age groups, the highest adjusted R^2 was obtained when more than one body measurement were included in the regression equation and suggests that weight could be estimated more accurately by combinations of two or more measurements than by girth alone.

5.8.1. Prediction Equations for Below One Month Age

Linear body measurements were found to be poor predictor for estimation of body weight for kids below one month age. This is in agreement made with the conclusion of Das *et al.* (1990) in Barbari and Jamunapari goats.

5.8.2 Prediction Equations for Three Months

In pooled sample at three months of age, chest girth alone could be used to predict the body weight. But in the case of females and males the second predictor was body length and height at withers respectively. Regarding singles and twins along with chest girth, height at withers was contributing much of the variation in body weight.

5.8.3 Prediction Equations for Six Months

At six months of age chest girth and height at withers were contributing to the much of the variation. This is in agreement with the findings of Badi *et al.* (2002) in Eritrean goat. Adjusted R^2 for best predicted equation in this age group varied from 60.3 to 73.4%.

5.8.4 Prediction Accuracy

There was no significant difference between predicted weight and actual weight in any of the age groups. This indicated that the equations can be used for the prediction of body weight from body measurements under field conditions. This result was comparable with the results of Thiruvenkadan (2005) in Kanni Adu.

5.9 SELECTION INDICES

The estimates of body weight, body measurements, peak yield, and genetic parameters of all these traits were calculated with the objective of formulating an index for selection of Malabari goats. Since all these traits contribute differently for the net economic profit, the relative economic value of each trait was also considered for the construction of selection indices.

5.9.1 Estimation of Relative Economic Value

The relative economic values for all the traits were calculated by taking into consideration the cost of production of each trait. Derivation of economic values were carried out on the basis of costs incurred on feed given to the goats, labour, supervisory and miscellaneous charges, and the average market rates at which the products were sold. This is in agreement with the findings of Rema (1985) in Malabari and crossbred goats, Rai *et al.* (2001b) in Marwari goats and Yadav *et al.* (2005) in Kutchi goats. The relative economic value of a trait is the value of one unit in comparison to the cost of one kg body weight at six months age. The relative economic value of sixth month body weight kept at unity as the main objective of constructing selection indices was to bring about maximum improvement in sixth month body weight. Singh *et al.* (1991) working in Black Bengal goats took the same criteria for calculating the relative economic value. The relative economic value for body weight, body length, height at withers and chest girth at below one, three and six months of age were estimated on the basis of simple regression of body weight at six months of age on these traits. The relative economic value of third month body weight was calculated as the ratio of cost value for per unit body weight of kids at three months of age and cost per unit of body weight at sixth month. The same method was adopted by Singh *et al.* (1969) in Haryana cattle and Singh *et al.* (1991) in Black Bengal goats. The economic value of peak milk yield was taken as the selling price of milk. Singh *et al.* (1969) used a similar method for calculation of economic value of milk yield.

The value was 1.3100 for body weight at three months and 0.7978 for body weight at below one month age. All body measurements have values ranging from 0.1868 to 0.3893. Milk yield has a lower value of 0.1547.

5.9.2 Selection Indices Involving Body Weights and Body Measurements

Indices were developed by incorporating various growth traits like body weight, chest girth, body length and height at withers at below one, three and six months of age by Henderson's modification of Hazel's method (Karam, 1953). The trait with highest correlation to body weight at six months of age was added first followed by others.

5.9.2.1 Sex Wise Selection Indices

Since males and females show difference in growth rate, indices were constructed separately for males and females.

5.9.2.1.1 Selection Indices for Males

Eleven selection indices were developed for males incorporating body weight and body measurements at below one, three and six months age. The correlation between index I and aggregate genetic worth H (r_{IH} values) of indices were between 0.4696 and 0.8267. The indices I_{6}, I_{7}, I_{8}, I_{9}, I_{10} and I_{11} had reasonably high (0.6225 to 0.8267) r_{IH} values. The corresponding values for rest of the indices were moderate in magnitude.

The index involving all the traits were considered to be 100% efficient and relative efficiencies of other indices were determined by using the efficiency of this index. The efficiencies of index I_7 to I_{10} were high in magnitude (63.50 to 90.38%). Excluding body length at below one month from an index involving all the traits caused 9.62% decline in relative efficiency whereas excluding of height at withers and body length at below one month caused 14.49% decline in relative efficiency as compared to the twelve variate index. This finding further revealed that the relative efficiency of index increased with the increase in the number of variants.

The aggregate economic genetic gain was highest for index no. I_{11} (6.3573) followed by tenth index (5.7460). The lowest value was obtained for index I_1 (1.3817). The aggregate genetic economic gain of indices increased with the increase in number of variants.

The expected genetic gain for each trait was positive in all cases. For index no. $I_{11,}$ I_{10} and I_9, the expected genetic progress in body weight at six months of age was 0.364, 0.339 and 0.318 kg respectively. The relative efficiencies and effectiveness of the indices were reasonably high except in the first four indices.

Taking into consideration the r_{IH}, aggregate economic genetic gain and genetic gain for individual traits of all the indices, the index no I_{11} ranked first followed by the indices I_{10} and $I_{9.}$ As such the use of eleventh index was expected to achieve more genetic gain in body weight at below one month (0.177 kg), three (0.238 kg) and six (0.364 kg) of age.

Khadanga *et al.* (1987) working on Ganjam goats, Singh and Singh (1999a) working on Jamunapari × Black Bengal goats and Rai *et al.* (2001b) studying Marwari goats constructed various selection indices in order to obtain maximum genetic gain.

5.9.2.1.2 Selection Indices for Females

Eleven selection indices incorporating twelve traits were constructed for females resulting in varying degrees of efficiency. The effectiveness of selection index depends upon its r_{IH} value and its aggregate economic genetic value. The r_{IH} values of indices were 0.3393 to 0.9881.

The index involving all the traits considered in this study was taken to be 100 per cent efficient in genetic sense and the efficiency of the rest of the indices was compared with this index. The efficiencies of the index I_7 to I_{10} were appreciably high (55.50 to 90.94 per cent). Excluding body length at below one month of age from the index incorporating all the traits caused a 9.06 per cent reduction in relative efficiency. Exclusion of both body length and height at withers at below one month of age resulted in 15.15 percent decline in relative efficiency.

The total genetic gains in terms of economic value of the traits as a result of application of a particular selection index was highest for I_{11} (6.4658) followed by I_{10} (5.8801). The aggregate economic genetic gain of indices increased with increase in number of traits.

The expected genetic gain was positive in all cases. Maximum genetic improvement for body weight at six months of age (0.826) was expected with the use of eleventh index followed by eighth index which incorporated body weight at below one, three and six months of age and body measurements at three and six months of age. The second index showed lowest genetic gain in body weight at six months of age.

Comparing all the indices for females based on r_{IH}, aggregate economic genetic gain and genetic gain for individual traits, the index $I_{11,}$ $I=0.6393 X_1 -0.1980X_2 -0.0709 X_3+ 0.6245X_4 + 01.7306X_5 -0.2740X_6 -0.5038X_7 -0.0417X_8 + 05.0545X_9 -0.6293X_{10} + 0.3482X_{11} -0.6915X_{12}$ seemed to be the best index to achieve more genetic gain in body weights at below one (0.308 kg), three (0.968 kg) and six (0.826 kg) months of age.

Similar results were obtained by Khadanga *et al.* (1987) in Ganjam goats, Singh and Singh (1999a) in Jamunapari × Black Bengal goats and Rai *et al.* (2001b) in Marwari goats.

5.9.2.2 Type of Birth Wise Selection Indices

Eventhough there was no significant difference between singles, twins and triplets in body weight at six months in this study, separate selection indices were constructed by taking into consideration the significant variations in early body weights.

5.9.2.2.1 Selection Indices for Single Births

Eleven selection indices were developed for males incorporating body weight and body measurements at below one, three and six months age. The r_{IH} values of indices ranged from 0.4848 to 1.9998. The r_{IH} values of all indices except the first three were more than the theoretical limits which indicated no significance except that high degree of relationship between index and aggregate merit of the genotype evolved. The indices with the r_{IH} values more than one had also been reported by Tomar and Singh (1980) in cattle and Singh and Singh (1999a) in goats.

The index involving all the traits were considered to be 100% efficient and relative efficiencies of other indices were determined by using the efficiency of this index. The efficiencies of index I_7 to I_{10} were high in magnitude. Excluding body length at below one month from an index involving all the traits caused 21.43%

decline in relative efficiency whereas excluding height at withers and body length at below one month caused 26.23% decline in relative efficiency as compared to the twelve variate index. This finding further revealed that the relative efficiency of index increased with the increase in the number of variants.

The aggregate economic genetic gain was highest for the twelve variate index no I_{11} (13.3635) followed by eleven variate index I_{10} (10.4993). The lowest value was obtained for two variate index I_1.

The expected genetic gain for body weight at six months of age was higher for selection based on index involving body weight and body measurements at below one, three and six months of age compared to other indices. The expected genetic gain for chest girth at six months of age turned out to be negative by the application of index I_2 and I_3 whereas the gain for chest girth at three months of age became negative by the application of index I_5, I_6, I_7, I_8 and I_{11}.

Taking into consideration the r_{IH}, aggregate economic genetic gain and genetic gain for individual traits of all the indices, index I_{11} ($I= -0.5923X_1\ -05.5593X_2 + 04.0386X_3 + 02.7690X_4 + 03.6035X_5 + \ 09.9151\ X_6\ -06.4886X_7\ \ -03.2629X_8\ \ -25.8698X_9 + \ 0.3289\ X_{10}\ -0.0574X_{11} + 08.1193X_{12}$) ranked first for selection of singles followed by I_{10} ($I= 02.440X_1\ \ -04.3426X_2\ \ 03.5799X_3\ \ 01.0883X_4\ \ -05.0457X_5\ \ 05.0820X_6\ \ -01.9303X7\ \ 0.4575X_8\ \ -07.5351X_9\ \ 0.1058X_{10}\ \ 01.1233X_{11}$).

5.9.2.2.2 Selection Indices for Twins

Eleven selection indices incorporating twelve traits were constructed for twins as well, which resulted in varying degrees of efficiency. The r_{IH} values of indices ranged from 0.3631 to 0.8205. The r_{IH} values of index I_7 to I_{11} were reasonably high

(0.6059 to 0.8205). The corresponding values for rest of the indices were moderate in magnitude.

The index involving all the traits considered in this study was taken to be 100 per cent efficient in genetic sense and the efficiency of the rest of the indices was compared with this index. The efficiencies of the index I_6 to I_{10} were appreciably high (65.36 to 96.16 per cent). Excluding body length at below one month age from the index incorporating all the traits caused a 3.84 per cent reduction in relative efficiency. Exclusion of both body length and height at withers at below one month age resulted in 12.10 per cent decline in relative efficiency.

The aggregate economic genetic gain for the traits as a result of application of a particular selection index was highest for I_{11} (5.1453) followed by I_{10} (4.9478). The aggregate economic genetic gain of indices increased with increase in number of traits.

The expected genetic gain for each trait was positive in all cases except for body weight and chest girth at below one month by the application of indices I_8 to I_{11}. Maximum genetic improvement for body weight at six months of age (1.008 kg) was expected with the use of eleventh index followed by tenth index (0.991 kg). The first index showed lowest genetic gain (0.390 kg) in body weight at six months of age.

Comparing all the indices for twins based on r_{IH}, aggregate economic genetic gain and genetic gain for individual traits, the index $I_{11,}$ $I= 0.1255X_1 -0.0374X_2 +0.2665X_3+ 0.1021X_4 - 0.8386X_5 -0.0951X_6+ 0.5411X_7 -0.3308X_8 -06.7760X_9 -0.4732X_{10} +0.3311X_{11}+ 0.3194 X_{12}$ seemed to be the best index to achieve more genetic gain in body weights at three months (0.950 kg) and six months (1.008 kg) of age.

Various selection indices with different growth traits were constructed by Khadanga *et al.* (1987) in Ganjam goats, Singh and Singh (1999a) in Jamunapari × Black Bengal goats, and Rai *et al.* (2001b) in Marwari goats.

5.9.2.3 Selection Indices for Pooled Data

Selection indices were developed using growth parameters of body weights and body measurements at below one, three and six months of age. Relative economic value calculated for each trait, based on the cost of production of each trait helped in improving the efficiency of the index.

The r_{IH} value of selection indices had a moderate to high value and the values ranged from 0.5226 to 0.7324. Aggregate economic genetic gain varied from 1.9653 to 6.2974.

Selection index constructed with body weight and chest girth had lowest relative efficiency of 31.21 per cent. From there onwards addition of each variable resulted in almost ten per cent increase in relative efficiencies in most cases. Excluding body length at below one month of age from the index incorporating all the traits resulted in 5.61 per cent reduction in efficiency, but exclusion of both height at withers and body length at below one month resulted in 15.35 per cent reduction in efficiency. Exclusion of body weight and body measurements at below one month caused a reduction of 34.24 per cent in efficiency.

On the basis of r_{IH} value and aggregate economic genetic gain the most efficient index, I= $0.1222X_1 + 0.4857X_2 + 0.4635X_3 -0.3158X_4 -0.5832X_5 -0.0308X_6 -0.2979 X_7 -0.038X_8 + 01.2742X_9 + 0.106X_{10} + 0.5035X11 -0.2857X12$

which incorporated all the traits under study. The expected genetic gains by the application of this index for body weight, chest girth, height at withers and body length at six months of age were 1.490 kg, 2.817 cm, 2.029 cm and 2.635 cm respectively. The r_{IH} value and aggregate economic genetic gain for this index were 0.7324 and 6.2974 respectively. As this index produced maximum genetic gain for individual traits also, this seemed to be the best index for pooled data.

Similar results were observed by Khadanga *et al.* (1987) in Ganjam goats, Singh and Singh (1999a) in Jamunapari × Black Bengal goats and Rai *et al.* (2001b) in Marwari goats.

5.9.2.4 Comparison of the Best Selection Indices among Different Groups

A comparison of different indices constructed sex wise, type of birth wise, and for pooled data has shown that index number 11 which incorporated all the traits *i.e.*, body weight and body measurements at different ages up to six months of age had highest r_{IH} values in all groups. Among the groups, the index with pooled data was considered to be most reliable as the number of sires used and number of progeny per sire was more (Table 4.25). So this index can be used for selection of Malabari goats under field conditions for increasing body weight.

5.9.3 Restricted Selection Indices

Restricted selection indices were constructed incorporating body weight and body measurements at below one, three and six months of age and by imposing restriction on body weight at below one month age. Restricted selection indices were constructed separately for females, males, singles, and twins and for pooled data.

The index obtained for males,

I_m= -0.9696 X_1+ 0.9266X_2 +0.5446X_3-0.1419X_4+0.1093 X_5+0.1403 X_6+-0.4910 X_7-0.6138X_8+2.5505 X_9+0.2765 X_{10} +0.2441 X_{11}-0.6889 X_{12}

with a r_{IH} value of 0.2577 was found to maximize the genetic gain in other characters. But the genetic advance in individual characters was less when compared to the index without restriction for males. In this case the expected genetic gain in the restricted character was found to be near to zero.

The restricted selection index for females by imposing restriction on the body weight at below one month was found to maximize the genetic gain in other characters. The genetic advance in all other characters due to selection of goats based on this index was comparatively less compared to that obtained with the index without restriction. Effective restriction was possible with the index as the genetic advance in body weight at below one month was zero.

The restricted selection index obtained for singles was found to be of no use with reference to this study as the r_{IH} value was negative and the genetic gain for individual characters could not be estimated.

The index obtained for twins by restricting body weight at below one month was found to maximize the genetic gain in other traits. Effective restriction was possible as the expected genetic gain in the body weight at below one month was zero. But the genetic advance in the individual characters was low when compared to the general selection index for twins incorporating body weights and body measurements.

The index obtained for pooled data by restricting body weight at below one month was found to maximize the expected genetic advance in most other traits. But by the application of this index, body length and chest girth at below one month and body weight at third month produced a negative gain. Effective restriction of body weight at below one month was possible as the expected genetic advance in the restricted character was equal to zero. The genetic gain expected by this method of selection was 0.630 kg for body weight at six months of age (Table 4.27).

The selection indices constructed by Singh *et al.* (1969) in cattle, Khadanga *et al.* (1987) in Ganjam goats, Singh and Singh (1999a) in Jamunapari × Black Bengal goats and Rai *et al.* (2001b) in Marwari goats involving various economic traits revealed varying degrees of efficiencies and effectiveness depending upon the traits used and number of traits as observed in this study also.

5.9.4 Selection Indices Involving Dam's Peak Yield and Body Weights and Body Measurements of Progeny

Incorporation of dam's productivity is not possible by Henderson's modification of Hazel's method (Karam, 1953). So in order to construct a selection index with dam's peak yield as one of the traits, together with body weight and body measurements of progeny at below one, three and six months of age, Hazel's method on the basis of path coefficient was used and the index was:

$I=-0.4474X_1 -0.2057X_2-0.0708X_3+ 0.7960X_4- 0.2434X_5+ 0.1424 X_6 -0.2816 X_7 - 0.3860 X_8 - 7.0463 X_9\ 0.9467 X_{10} +0.6469 X_{11} +0.5184X_{12}+0.0001X_{13}$

This index was constructed with the objective of increasing milk production together with the body weight at different ages, as Malabari is a dual purpose goat breed. The efficiency of this index could not be compared with the other indices as the method adopted was different. Similar indices were constructed by Hazel (1943) in pigs.

From this study aimed at construction and comparison of different selection indices in Malabari goats, it is found that a genetic gain of 1.490 kg is expected in the next generation, if selection is made based on the index constructed including body weights and measurements *i.e.* body length, height at withers, and chest girth at below one, three and six months of age by using Henderson's modification of Hazel's method. The above indices can be effectively utilized for increase in body weight in Malabari goats, which is also expected to increase the milk production, since a high and significant correlation exists between body weight and peak yield in Malabari goats. For simultaneous selection of both growth and milk production the index developed using path coefficient method was found to be useful. But the disadvantage was that the data pertaining to this index belonged to two different generations. The restricted selection index gave a genetic gain of only 0.630 kg which was less than half of the first index. So the most efficient index for selection of Malabari goats under field conditions as per the present study is the index constructed by taking into consideration the body weights and body measurements at different ages up to six months of age.

SUMMERY

6. SUMMARY

Selection is one of the basic tools available to animal breeders for genetically improving populations, and is the classic means by which seed stock breeders effect genetic change. In order to optimize the genetic improvement of Malabari goat population in North Kerala, a selection criterion is found to be necessary. Hence a study was conducted with the objective of construction of different selection indices and selecting the best index by comparing their effectiveness, by incorporating various growth traits and peak yield. The study was conducted based on the data collected from the farmers' flocks formed under All India Co-ordinated Research Project (AICRP) on goats for Malabari goat improvement. A total of 1055 records of animals born from August 2005 to August 2008 were collected. Traits of economic importance used in this study were body weight, chest girth, body length and height at withers at below one, three and six months of age as well as peak yield of dam.

Least square analysis was performed to find the effect of non genetic factors on various traits. The body weight and body measurements at below one, three and six months of age were adjusted for centre, sex, type of birth, year of birth and season of birth. The overall least square mean body weights recorded were 3.12±0.11, 8.28±0.18 and 15.99±0.33 kg respectively for below one, three and six months of age. Centre had significant effect on body weight at below one, three and six months of age and kids born in Badagara weighed higher at all ages followed by Tellichery and Tanur born kids. Effect of sex was also significant at all stages. Males had higher body weight at all the ages studied. The average body weights for males were 3.21±0.13, 8.50±0.20 and 16.40±0.37 kg at below one, three and six months of age respectively and for females the values were 3.03±0.12, 8.06±0.19 and15.58±0.34 kg respectively. Type of birth had significant effect on body weight at below one and three months of age only. Kids born singly had higher body weight in these ages

followed by twins and triplets. Year of birth had significant effect on body weights at third and sixth month. Effect of season was significant for body weight at below one and three months of age but was non significant at six months of age.

The overall mean of chest girth at below one, three and six months of age were 35.47±0.45, 46.12±0.46 and 56.67±0.58 cm respectively. Corresponding values for overall means of body length were recorded as 32.49±0.50, 42.30±0.46 and 50.51±00.63 cm. The overall mean heights at withers at below one, three and six months of age were 35.67±0.46, 45.17±0.45 and 55.32±0.58 cm respectively. The centre of recording had significant effect on body measurements at below one, three and six months of age. Badagara born animals had higher body measurements in all the age groups followed by Tellichery and Tanur born kids, except for body length at sixth months. Males recorded higher body measurements at all ages studied and the effect of sex was significant. Type of birth had significant effect on body measurements at below one and three months of age. But the effect of type of birth was found to be non significant in the body measurements at six months of age except for body length. Year and season of birth had significant effect on body measurements at all the ages studied.

Peak yields of milk in Malabari goats were recorded and the mean peak yields recorded was 1237.62± 75.44 ml. To study the non genetic effect of centre, year and season of kidding, peak yield was subjected to least square analysis. The centre had significant effect on peak yield. Badagara animals yielded more milk (1978.28 ±113.60 ml) compared to the Tellichery and Tanur animals. Year and season of kidding also played a significant role on the peak yield of Malabari goats. The animals kidded in the year 2008 had higher average peak yield (1370.71±102.12 ml) followed by those in others. The animals kidded in the winter season registered the highest mean peak yield (1400.40 ±77.37 ml) followed by those kidded in summer and rainy season.

The percentage of singles, twins, triplets and quadruplets were 24.00, 61.47, 13.19 and 1.05 respectively in the total population under study during the period. The percentage of multiple births was higher in Tanur (79.29%) than in Badagara (74.87%) and Tellichery (74.56%).

The data adjusted for non genetic effects were used for the estimation of genetic parameters. The heritability estimates of body weights at below one, three and six months of age were 0.636± 0.436, 0.023±0.229 and 0.799±0.476 respectively. The heritability was also estimated for body measurements, and for body measurements at below one and six months of age, heritability estimates were high whereas for three months of age they were low to moderate. Genetic and phenotypic correlations were estimated for body weight and body measurements. Positive genetic correlations were reported in most of the cases except the theoretical exceeded cases and between body weights at three and six months of age. Exceptional cases may be due to low sample size. The phenotypic correlations estimated between body weight and body measurements at below one, three and six months of age were positive and the values ranged from 0.078±0.108 (chest girth at birth and sixth month) to 0.833± 0.060 (between body length and chest girth at six months of age).

The heritability estimate of peak yield was 0.846±0.561. Genetic and phenotypic correlations were estimated between peak yield and body weight and measurements. Genetic correlation coefficients estimated with peak yield to body weight and body measurements were positive and significant except with chest girth at six months of age. They ranged from 0.08 (for chest girth at sixth month and peak yield) to 0.88 (for peak yield and body weight at third month). Phenotypic correlations were positive except with body length and chest girth at six months of age.

Prediction equations were developed for estimation of body weight using chest girth, paunch girth, body length and height at withers for below one, three and six months of age. Predictions equations were developed sex wise, type of birth wise, centre wise and for pooled data. The best fitted regression equations in each group was selected and the predicted bias was found to be non significant in all the groups. Linear body measurements were found to be poor predictors for estimation of body weight for below one month of age. Chest girth accounted for maximum variation in most of the cases. In all the age groups the highest adjusted R^2 was obtained when more than one body measurements were included in the regression equations, suggesting that weight could be estimated more accurately by combination of two or more measurements than by chest girth alone.

The phenotypic and genetic parameters estimated in the present study were utilized to construct different selection indices in Malabari goats. Cost of production for individual traits was calculated. The relative economic value of six month body weight was kept at unity as the main objective of constructing selection indices was to bring about maximum improvement in body weight at six months of age, and the relative economic values of other growth traits except body weight at three months of age were estimated on the basis of simple regression of six month body weight on these traits. The relative economic value of body weight at three months of age was calculated as the ratio of cost per unit of body weight of kids at three months of age and cost per unit of body weight at six months of age.

Selection indices were developed using body weights and measurements as well as body weight, measurements and peak yield of dam. Indices were developed sex wise, type of birth wise and for pooled data. For males, selection indices developed had r_{IH} value ranging from 0.4696 to 0.8267. The aggregate economic genetic gain was highest for index no.I_{11} (06.3573) followed by tenth index (05.7460). The expected genetic gain for each trait was positive in all cases and the highest genetic gain was expected with the index I_{11} for body weight at six months of age (0.364kg). So comparing these, eleventh index incorporating all body weights and measurements ranked first followed by the indices I_{10} and I_9.

Eleven selection indices were developed for females also, utilizing various growth traits. The r_{IH} values of indices were 0.3393 to 0.9881. The total genetic gains in terms of economic value of the traits as a result of application of a particular selection index was highest for I_{11} (06.4658) followed by I_{10} (05.8801). The efficiencies of the index I_7 to I_{10} were appreciably high (55.50 to 90.94 per cent) when comparing with the $I_{11.}$ Maximum genetic improvement for body weight at six months of age (0.826) was expected with the use of eleventh index followed by eighth index. By comparing all the indices for females based on r_{IH} , aggregate economic genetic gain and genetic gain for individual traits, the index I_{11} is the best to achieve maximum genetic gain in various traits.

Selection indices were also constructed separately for singles and twins. Eleven selection indices were developed for singles incorporating body weight and body measurements at below one, three and six months of age. The r_{IH} values of indices ranged from 0.4848 to 01.9998. Apart from $I_{11,}$ the efficiencies of index I_7 to I_{10} were high in magnitude. The aggregate economic genetic gain was highest for twelve variate index no I_{11} (13.3635) followed by eleven variate index I_{10} (10.4993). The expected genetic gain for body weight at six months of age was higher for selection based on the index involving body weight and body measurements at below one, three and six months of age compared to other indices. Because of these reasons, index I_{11} ranked first for selection of singles, followed by I_{10}.

Eleven selection indices incorporating twelve traits were formulated for twins as well which resulted in varying degrees of efficiency. The r_{IH} values of index I_7 to I_{11} were reasonably high (0.6059 to 0.8205). The efficiencies of the index I_6 to I_{10} were appreciably high (65.36 to 96.16 per cent) when compared with $I_{11.}$ The eleventh index (5.1453) followed by tenth index (4.9478) had the higher gains. Maximum genetic improvement in body weight at six months of age (1.008 kg) was expected with the use of eleventh index but the application of this index caused a negative impact on the genetic gain for body weight (-0.147 kg) and chest girth (-0.544 cm) at below one month of age. By comparing all the indices for twins the index I_{11} seemed to be the best index to achieve more genetic gain in body weights at three months (0.950 kg) and six months (1.008 kg) of age.

Eleven indices were constructed using body weights and body measurements like chest girth, body length and height at withers at below one, three and six months of age from the pooled data also. The r_{IH} value of selection indices had a moderate to high value. Selection index constructed with body weight and chest girth had lowest relative efficiency of 31.21 per cent. From there onwards addition of each variable resulted in almost ten per cent increase in relative efficiencies in most cases. The index involving all the traits had maximum aggregate economic genetic gain of 6.2974. When selection was based on index I_{11}, the expected genetic progress in body weight at six months of age was 1.490. On the basis of r_{IH} value and aggregate economic genetic gain the most efficient index was the index I_{11} which incorporated all the growth traits under study.

An index was also constructed with the objective of increasing milk production together with the body weight at different ages by incorporating dam's peak yield as one of the traits. This index had the r_{IH} value of 0.5703.

Restricted selection indices were constructed by imposing restriction on body weight at below one month and the genetic gains were calculated. They were developed separately for males, females, singles, twins and for pooled data. Effective restriction of body weight at below one month was possible in all the cases. The genetic advance in all other characters due to selection of goats based on this index was comparatively less than that obtained with the index without restriction.

The present study revealed that selection of superior individuals with an index incorporating various growth traits will increase the rate of genetic progress to a greater extent as compared to any other method of selection.

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CONSTRUCTION AND COMPARISON OF THE EFFICIENCY OF DIFFERENT SELECTION INDICES FOR MALABARI GOATS

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Abstract of the thesis submitted in partial fulfilment of the requirement for the degree of

Master of Veterinary Science

Faculty of Veterinary and Animal Sciences
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2009

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ABSTRACT

The study was conducted with the objective of optimizing the genetic improvement of Malabari goat population in North Kerala by adopting an index method of selection incorporating various growth traits and peak yield of dam. Present study was undertaken on 1055 records of animals born from August 2005 to August 2008 from the farmers' flocks of AICRP on goats for Malabari goats.

Effect of non-genetic factors on body weight and body measurements at below one, three and six months of age was analyzed. Effect of centre and sex had significant influence on body weight and body measurements of all the ages studied. Type of birth had significant effect on body weight and measurements at below one and three months of age, but the same was non significant at six months of age except for body length. Year of birth had significant effect on body weights at third and sixth month, where as the effect of season was significant for body weight at below one and three months of age. But the effects of these factors on body measurements were significant at all the ages studied.

Milk production in Malabari goats was recorded as peak yield and the mean peak yield recorded was 1237.62± 75.44 ml. The effects of centre, year and season of kidding had significant influence on peak yield.

A high percentage of multiple births (75.71%) was recorded in the in the total population under study during the period for Malabari goats. The percentage of multiple births was higher in Tanur (79.29%) than in other centres.

Heritability estimates were high for body weight and measurements at below one and six months of age and for peak yield also, whereas for three months of age

they were low to moderate. Correlations between the traits were positive in almost all cases. The relative economic values of various traits were derived. Taking into consideration the heritability, genetic and phenotypic correlations as well as relative economic value, selection indices were constructed.

Selection indices were developed by incorporating body weight and body measurements at below one, three and six months of age. Index with all the traits under study (I_{11}) was expected to achieve more genetic gain in body weight at six months of age in all the groups. By taking into consideration, the r_{IH} and aggregate economic genetic gain also, the same index was found to be the best in each group. Among the groups, the index with pooled data was considered to be most reliable and expected to achieve more gain in body weight at six months (1.490 kg) of age.

Restricted selection indices by imposing restriction on body weight at below one month were also constructed. Effective restriction was possible in all the cases. The genetic advancement in all other characters due to selection of goats based on this index was comparatively less to that obtained with the index without restriction.

To increase milk production along with body weight, a selection index was constructed with dam's peak yield as a trait along with the growth traits of progeny.