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Evaluation of growth rates and resistance to nematodes of Deccani and Bannur lambs and their crosses with Garole

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Abstract

Sheep rearing is a traditional occupation of about 85 000 shepherd families on the Deccan plateau in the Maharashtra State of India. They rear Deccani (D) sheep which usually bear only single lambs. Prolificacy is an important trait for the efficiency of meat producing sheep. It was decided to evaluate and utilize Indian sheep genetic resources with a view to improving the efficiency of sheep production on the Deccan plateau. A crossbreeding experiment was conducted over 4 years, using rams of the D, Bannur (B) and Garole (G) breeds and D and B ewes with the aim of developing recommendations for the appropriate breed combination of a likely composite. It was found that crossing with G reduces live weight and growth rates significantly compared with D but lambs sired by G rams were more resistant to naturally acquired gastro-intestinal nematode infections and to artificial challenge with Haemonchus contortus *than those sired by D or B rams. The G breed, being from a humid environment is, however, not adapted to the semi-arid Deccan plateau. The higher productivity (in terms of weight of lamb weaned) of twin-bearing ewes compared with those bearing singles was evident even in extensive rearing conditions. The finding of increased resistance to gastro-intestinal nematodes in the G breed, which also carries a major gene for prolificacy, highlights the potential for inclusion of G in a composite breed. Negative effects on growth and survival from inclusion of the Garole need to be carefully managed.*

Keywords: *crossbreeding, growth rate, nematoda, prolificacy, sheep.*

Introduction

Maintaining grazing flocks of sheep for meat and manure is a traditional occupation of about 85 000 families of the 'Dhangar' and other communities on the semi-arid Deccan plateau in the Maharashtra and Karnataka states of India. Sheep play a positive rôle in the local agricultural production system, by utilizing low quality crop residues and grasses, converting these to meat, wool and skins and providing manure to cropped lands. The local breed of sheep, the Deccani, is a medium sized (27 kg mature weight), leggy breed that varies widely in colour and produces a short coarse fleece (600 g/year). The sale price of the coarse wool produced is commonly insufficient to cover the cost of shearing and lamb production contributes more than 90 percent of the income from sheep-rearing.

Meat production in India is projected to barely satisfy the demand by 2020, despite the low projected demand of only 6 kg per person per annum (Delgado *et al.*, 1999). Mild to moderate protein-energy malnutrition affects up to one-third of all children and perhaps a higher share of pregnant or lactating women in the developing world, including India (Delgado *et al.*, 1999). Increased consumption of relatively small additional amounts of meat and milk could make up the dietary deficits in protein and micronutrients and much of the dietary deficit in energy, especially in children. There is therefore an urgent need to increase meat production and availability, in the developing world, including India.

Deccani sheep usually produce only single lambs, a serious limitation to their biological efficiency for meat production. Great potential exists to increase sheep productivity and efficiency by increasing reproductive rate through exploitation of genetic variation within and between breeds (Kukovics, 1986). Achievement of modest increases in prolificacy that are consistent with existing production resources i.e. seasonal plentiful food availability, would improve sheep productivity substantially.

Gastro-intestinal parasites, mainly *Haemonchus contortus*, are perceived to be one of the major constraints to profitable sheep production in India. The reasons for this are many and varied; such as a large animal population, rapidly diminishing grazing areas with consequent overstocking and poor quality food resources (Chowdhury, 1994).

It was therefore decided to investigate the advantages to be gained by introducing prolificacy, improved carcass conformation, a reduction in the required frequency of shearing and superior resistance to internal parasites into Deccani sheep using other breeds. The chosen breeds having one or more of these attributes, were the prolific but small, coarse-wooled Garole breed from Sunderban in West Bengal State (Ghalsasi and Nimbkar, 1993) and the Bannur (also called 'Bandur' or 'Mandya') breed of hair sheep from adjoining Karnataka State. The Garole is the only known prolific Indian sheep breed (Fahmy and Mason, 1996) with an average litter size of 1·68 (Sharma *et al.*, 1999) to 1·74 (Nimbkar *et al.*, 1998). The Bannur was found to be a hardy sheep with good survivability under harsh conditions, in studies undertaken at the Nimbkar Agricultural Research Institute (NARI). The Bannur also has the best conformation of all Indian meat sheep breeds (Acharya, 1982). The Deccani and Bannur breeds are adapted to a hot, dry climate while the Garole is native to the delta of the Ganges river, which is a hot, humid and swampy region. It was expected that the Garole may be poorly adapted to the arid conditions on the Deccan plateau but may have some resistance to nematodes because their native habitat is highly conducive to gastro-intestinal (GI) nematode parasites.

The objectives of this study were therefore to test whether the Garole is more resistant to worms, although of small size, compared with the other breeds in the study and whether crossing the Deccani with Bannur would introduce hair characteristics and reduce the required frequency of shearing without compromising growth rates or resistance to GI nematodes. Although the Garole comes from a humid environment, it was used in this study since it was the only prolific breed available in India. A crossbreeding experiment was conducted over a 4-year period, using Deccani, Bannur and Garole rams and Deccani and Bannur ewes with the aim of evaluating the growth and resistance to GI nematodes of the breeds and crosses among them. The study was also expected to provide estimates of genetic variation in growth and resistance traits to indicate to what extent these traits would be amenable to selection. Detailed evaluation of reproductive performance and maternal traits will follow in a separate paper.

Table 1 *Number of rams of each breed used for the breeding programme in each year†*

Year	Ram breed		
	Garole (G)	Bannur (B)	Deccani (D)
1996	3	5	3
1997	3	5	4
1998	8	6	5
1999	9	7	5
Total no. of different rams used	16	10	6

† Two D and three B rams used every year, one G and one D ram used for 3 years.

Material and methods

Experimental design

A complete 3 × 3 diallel breeding design with the Deccani (D), Bannur (B) and Garole (G) breeds was planned but could not be achieved. This was due to insufficient number of G ewes being available and the problems of managing the small G ewes in the same grazing system as the larger D and B ewes. Garole ewes were found to be poorly adapted to the dry, harsh grazing conditions in Maharashtra which differed markedly from the humid and swampy conditions in the area where the breed originated. Therefore, an incomplete diallel breeding

Table 2 *Number of lambs born each year classified by genotype*

Sire	Dam	Year				Total
		1996	1997	1998	1999	
Garole	Deccani	20	20	24	18	82
	Bannur	12	12	23	16	63
Bannur	Deccani	20	20	39	17	96
	Bannur	15	12	21	13	61
Deccani	Deccani	22	22	35	26	105
	Bannur	13	11	21	18	63
Total		102	97	163	108	470

programme, using rams of all three breeds but only D and B ewes, was carried out for four years from 1996 to 1999 inclusive. Six D, 10 B and 16 G rams were used; out of which two D and three B rams were used in each of the 4 years (Table 1). All D rams and some of the G and B rams used were purchased from other flocks and assumed to be unrelated. Two G rams and four B rams used in 1998 and 1999 were sons of those used in 1996. Semen collected from each ram was used to inseminate ewes of both D and B breeds. The number of lambs born of each genotype in each year is shown in Table 2.

Location and ewe management

The experiment was carried out at Phaltan, situated at latitude 18° north and longitude 74° east, 110 km south-east of Pune on the Deccan plateau. The average annual rainfall in this area is 525 mm and 80 percent of it falls between August and October. The dry season lasts from November to May during which period, there is usually no precipitation.

All D and B ewes were ear-tagged and run together. They were constrained to one lambing per year. Ewe management was kept as similar to that of local non-migratory shepherds' flocks as possible. Ewes were grazed on natural and improved pastures which were sometimes irrigated, and seasonally on crop residues in harvested fields and in pomegranate orchards. They were housed in sheds at night, except during summer when they were yarded on empty fields for manuring. They were shorn twice a year – in January and July. Ewes were offered maize grain or concentrate (every 100 kg comprising of 40 kg maize, 20 kg deoiled rice bran, 15 kg sunflower extract, 11 kg rice polish, 10 kg molasses, 1 kg urea, 1 kg salt, 1 kg calcite and 1 kg mineral mixture) at 100 g per head per day for flushing, from 10 days before the artificial insemination (AI) programme to the end of the programme every year. They were not given any concentrate at any other time. All rams and ewes were vaccinated annually against enterotoxemia and haemorrhagic septicaemia (using vaccines produced by the Institute of Veterinary Biological Products (IVBP), Government of Maharashtra, Pune). Ewes were culled for failure to conceive, old age and chronic health problems. No other selection was imposed during this study.

Because of the small size of G rams relative to the D and B ewes, cervical AI was adopted as the method of breeding. Ewes were inseminated at natural oestrus (detected by vasectomized teaser rams) for a period of two to four oestrous cycles during June to August each year with fresh, diluted semen. The composition of the semen diluent used was based on one suggested by Evans and Maxwell (1987) and modified for local conditions, to include 8·33 g Tris, 2·5 g D-glucose, 4·55 g citric acid (monohydrate), 250 mg Streptomycin sulphate, 250 000 i. u. Penicillin and glass distilled water to 250 ml. Lambs were born between November and January. The difference in age between the youngest and the oldest lamb in each year was not more than 75 days.

Lamb management and weight recording

Lambs were identified with ear tags within 1 h or 12 h of birth according to whether born during the day or night. Lambs were weighed and their pedigrees, descriptions and birth weights recorded. Thereafter, they were weighed every month on electronic weighing scales (Essae-Teraoka Limited, Bangalore) to the nearest 0·1 kg until the age of 6 months. Lambs remained indoors and were stall-fed with green *Leucaena leucocephala* leaves until the age of one month when they commenced grazing with their dams. They were not given any other supplementary food at any time. While stall-fed, lambs were penned with their dams at night. Lambs were vaccinated against enterotoxemia twice during the first month of life with a 2-week interval between the subsequent doses. Male lambs were castrated at the age of 2·5 to 3 months, using either elastrator rings or a Burdizzo's castrator in different years. Two or three male lambs of the chosen genotypes according to an assessment of future requirement of breeding rams, were selected, based on their growth rates and pedigree information, every year before castration and separated from the experimental flock at weaning. The other male lambs were sold after the artificial challenge with worms.

All lambs were always run together. They were removed from their mothers and grazed separately for a 1-month period after weaning. At all other times, they grazed in the same flock as their mothers, except in 1999 when lambs were not sent back into the ewe-flock after weaning. In 1996 and 1997, lambs were weaned at the age of 2·5 to 3 months. In 1998, they were weaned when they reached 14 kg body weight or 4 months of age. The average ages at weaning in 1998 and 1999 were 112 and 125 days respectively, which is similar to the age at which local shepherds sell male lambs. Female lambs for replacement in village flocks are not weaned and they are always in the same flock as their mothers.

Lambs were shorn at the same time as the ewes. Since ewes were shorn twice a year, in January and July, lambs born in November-December were shorn first at the age of 7 to 8 months in July of the next year. Male lambs born in 1996 and 1999 were not shorn since they were to be sold soon after July and unshorn lambs usually fetch higher prices.

Monitoring of faecal worm egg count (FEC) and packed cell volume (PCV)

Faecal worm egg count (FEC) of lambs was measured, using the modified McMaster method (Ministry of Agriculture, Fisheries and Food (MAFF), 1986), monthly from the age of 3 months. The minimum level of detection was 100 eggs per gram (e.p.g.) of faeces. After determination of FEC, the faecal samples were pooled and cultured at 27ºC for 7 days. L-3 stage larvae were harvested from the culture and stained with Gram's iodine and the morphology of at least 100 larvae was studied for species differentiation. Larval species were identified by observation of the head and tail regions of the larvae as described by MAFF (1986). Larvae were exsheathed if necessary for species identification.

Lambs did not develop sufficiently high FEC from natural challenge to allow comparison of resistance to GI nematodes of different genotypes. Therefore, in 1997, 1998 and 1999, lambs were artificially challenged with a local strain of *H. contortus* isolated and multiplied at NARI. Lambs born in 1996 were not challenged artificially. At the time of the artificial challenge, the 1997, 1998 and 1999-born lambs were 8 to 10 months, 10 to 11 months and 6 to 8 months old, respectively. The 1997 and 1999-born lambs were each orally dosed with 10 000 L-3 larvae while the 1998-born lambs received 4000 L-3 each due to reduced availability of larvae. FEC was determined at days 21 and 26 post infection. The infections were terminated on day 28 post infection.

The packed cell volume (PCV) of blood from lambs born in 1998 and 1999 was determined using the microhaematocrit method. PCV of lambs was measured the next day after deworming prior to artificial infection and on days 15 and 27 post infection.

Lambs born in 1996 were first dewormed at 1 year of age. Lambs born in 1997, 1998 and 1999 were given a pre-treatment drench before infecting them with *H. contortus* larvae and a second treatment to terminate the infection on the 28th day post infection. In all cases, sheep were drenched with the recommended dose (5 mg/kg body weight) of albendazole (Analgon, Wockhardt Veterinary (India) Limited, Mumbai). The drench was always fully effective which was ensured by measuring the FEC of at least 40% of the sheep 10 to 14 days after every drenching.

Traits studied and statistical analysis

Lamb production traits analysed were birth weight (BWT), weight at 3 months (WT3), average daily gain from birth to 3 months (ADG3), weight at 6 months (WT6) and fleece weight at first shearing (WOOL1). Lamb mortality from birth to 3 months (MORT0-3) and from 3 to 6 months of age (MORT3-6) was also analysed. Weight of 3-month-old lamb produced per ewe lambing was analysed as a trait of the ewe. Lamb weights were adjusted to the average age of 88·5 days for this analysis. If the lamb had died before reaching that age, weight of lamb produced was considered to be zero.

All data were analysed using Harvey's mixed model least squares and maximum likelihood computer program (Harvey, 1990) and also the ASREML package (Gilmour *et al.,* 1999). Two mixed models were fitted. The first one included, where significant, the fixed effects of breed of sire, sex, year of birth, type of birth, breed of dam, dam's duration at NARI, parity group of dam (all dams divided into three parity groups; first, second and third or more) and the random effect of sire ('sire nested within breed' for the Harvey analysis). Age of lamb on the weighing date for WT3 was fitted as a regression variable for the analysis of WT3. Age of the lamb on the weighing date was excluded from the model for the analysis of WT6 as it was not significant. The second model fitted included all the fixed effects, except breed of sire and breed of dam, and regressions on D and B direct breed effects, maternal effect of D breed (DMAT) and heterosis between D and B (and reciprocal) crosses (HDB) and between G and D crosses (HGD). Because of the nature of the breeding design, DMAT estimates the difference in maternal ability between D and B, and HGD estimates the difference between HGD and heterosis between G and B breeds (HGB). Heritability was estimated as four times the sire variance divided by phenotypic variance. The 'dam's duration at NARI' effect was fitted to distinguish between the B and D ewes that were at NARI for about 4 years before the experiment and those newly purchased (B ewes once in 1998 from Karnataka and D ewes in 1997 and 1998 from locations within a radius of 35 km from Phaltan). Dams themselves born at NARI during the first 2 years of the experiment were included in the same group as the dams originally at NARI. Birth fortnight (duration of the lambing period being divided into four or five fortnights per year) was fitted but excluded from the final model since it was not significant. All non-significant interactions were excluded from the final analyses of weight and growth traits and mortality.

The FEC measurements after natural challenge (NATFEC) of lambs born in 1996, 1998 and 1999 were analysed. NATFEC were not analysed for 1997 as they were very low (average FEC < 100 e.p.g.). A repeated measures model in the ASREML program was used for the analysis of NATFEC with one FEC

Table 3 *Least-squares means and standard errors of lamb birth weight (BWT), weight at 3 months (WT3), weight at 6 months (WT6) (kg) and growth rate from birth to 3 months (ADG3) (g/day) for breed of sire and breed of dam effects†*

	Trait							
	BWT		WT3		ADG3		WT6	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Overall mean	2·0 (451)	0·1	8·8 (396)	0·4	78·7 (396)	3·6	12·6 (308)	0·4
Breed of sire								
Garole	1·7 [a] (138)	0·1	8·0 [a] (126)	0·5	71·5 [a] (126)	4·1	10·6 [a] (88)	0·5
Bannur	2·0 [b] (154)	0·1	9·0 [b] (146)	0·5	81·5 [b] (146)	4·0	13·2 [b] (121)	0·5
Deccani	2·2 [b] (159)	0·1	9·3 [b] (124)	0·5	83·2 [b] (124)	4·2	14·0 [b] (99)	0·6
Significance	***		***		**		***	
Breed of dam								
Bannur	1·9 [a] (178)	0·1[a]	8·4 [a] (158)	0·5[a]	75·8 [a] (158)	4·0[a]	12·2 [a] (120)	0·5[a]
Deccani	2·0 [b] (273)	0·1	9·1 [b] (238)	0·4	81·7 [b] (238)	3·5	13·0 [b] (188)	0·4
Significance	**		**		*		*	

[a,b,c] Within each comparison, means not sharing a common letter in the superscript are significantly different ($P < 0·05$).
† Figures in brackets are numbers of observations.

measurement for lambs born in 1996, five FEC measurements 15 days apart for lambs born in 1998 and two FEC measurements two months apart for lambs born in 1999. Lambs were not drenched between measurements.

For the analysis of artificial challenge FEC in 1997, 1998 and 1999, a repeated measures model in the ASREML program, using two FEC measurements on days 21 and 26 post artificial challenge (ARTFEC) was used. NATFEC and ARTFEC were cube-root transformed ($FEC^{0·33}$) to normalize FEC data and reduce the range of variances between years from 276-fold to 2·4-fold for NATFEC and 110-fold to 2·2-fold for ARTFEC (Woolaston and Piper, 1996). Both the NATFEC and ARTFEC data were also analysed separately yearwise to make sure the results did not differ from the repeated measures analysis.

Normal PCV of lambs (before artificial challenge), PCV on day 27 post infection and the change in PCV between the base PCV and PCV on days 15 and 27 post infection (PCVD15 and PCVD27) were also analysed. The fixed effects fitted for FEC and PCV traits were breed of sire, year of birth, breed of dam and duration of dam at NARI. Sex, type of birth and

Table 4 *Least-squares means and standard errors of fleece weight (g) at first shearing (WOOL1) for breed of sire and breed of dam and their interaction*

		WOOL1	
	No. †	Mean	s.e.
Overall mean	211	285	22
Breed of sire			
Garole (G)	58	224 [a]	28
Bannur (B)	86	298 [b]	27
Deccani (D)	67	333 [b]	25
Significance		***	
Breed of dam			
Bannur (B)	79	261 [a]	24
Deccani (D)	132	309 [b]	22
Significance		**	
Breed of sire × breed of dam			
G × B	22	233 [a]	32
G × D	36	215 [a]	27
B × B	28	259 [ac]	32
B × D	58	336 [b]	24
D × B	29	290 [c]	29
D × D	38	376 [b]	24
Significance		*	

[a,b,c] Within each comparison, means not sharing a common letter in the superscript are significantly different ($P < 0·05$).
† No. = number of animals.

parity group of dam were not included in the models for any of the FEC and PCV traits as they were not significant. A random sire effect was fitted for ARTFEC (but not for NATFEC since there was little sire variance) and for PCV.

Results

Lamb weight, growth rate, lamb mortality and fleece weight

The least-squares means for the significant fixed effects of breed of sire and breed of dam, of all weight and growth traits analysed, fleece weight at first shearing and lamb mortality, are presented in Tables 3, 4 and 6 respectively.

Breed of sire and sire effects. Breed of sire had a significant effect on BWT, WT3, WT6, WOOL1, (all $P < 0{\cdot}001$), weight of 3-month-old lamb produced per ewe lambing and ADG3 (both $P < 0{\cdot}01$). Lambs of D sires were the heaviest, followed by lambs of B and lastly by lambs of G sires at birth, 3 months and 6 months of age, although lambs of B and D sires did not differ significantly and had nearly identical ADG3. Similarly, the least squares mean fleece weight of D-sired lambs was the highest followed by B-sired and lastly by G-sired lambs. The differences between live weights of D-sired and G-sired lambs were, 0·5 kg, 1·3 kg and 3·4 kg at birth, 3 months and 6 months respectively.

Estimates of sire variances, phenotypic variances and heritabilities of weight and wool traits are given in Table 5. The estimated heritabilities of BWT, WT3, WT6 and WOOL1 were, 0·03 (s.e. 0·08), 0·15 (s.e. 0·12), 0·39 (s.e. 0·22) and 0·43 (s.e. 0·25) respectively.

Individual heterosis (HGD and HDB) was not significant for any of the weight or growth traits. There was significant negative individual heterosis among GD crosses (HGD) for WOOL1 (–1·0 (s.e. 0·32)) which implies the opposite effect in GB crosses. However, there was no significant negative individual heterosis for WOOL1 in DB crosses. The direct and maternal effects of the D breed were not significant for any of the weight, growth or wool traits. However, there was a significant negative direct effect of the B breed on BWT, WT3, ADG3 and WT6. The direct effect of the B breed was not significant for WOOL1.

The highest mortality up to the age of 3 months and from 3 to 6 months was among lambs of G sires (18·8% and 6·7%, respectively) compared with lambs of B (12·1% and 4·0%) and D sires (14·4% and 5·0%), although the effect of breed of sire was not significant (Table 6). The major causes of mortality were pneumonia, enteritis and general debility due to poor milk yield of the dam.

Table 5 *Estimates of sire variance, phenotypic variance and heritability for weight and wool traits*

Trait	Sire variance (kg^2)	Phenotypic variance (kg^2)	Heritability h^2	s.e.
BWT	0·003	0·311	0·03	0·08
WT3	0·159	4·196	0·15	0·12
ADG3	0·014	0·471	0·11	0·11
WT6	0·623	5·698	0·39	0·22
WOOL1	0·001	0·010	0·43	0·25

Table 6 *Least-squares means (LSM) and standard errors for lamb mortality (%) from birth to 3 months, and 3 to 6 months for all fixed effects of breed of sire and breed of dam*

	Mortality: Birth to 3 months				Mortality: 3 to 6 months			
	Lambs born†	Lambs died†	Mortality Mean	s.e.	Lambs alive at 3 months†	Lambs died†	Mortality Mean	s.e.
Overall mean	470	31	15·1	4·7	439	10	5·2	2·5
Breed of sire								
Garole	145	15	18·8	5·4	130	5	6·7	2·8
Bannur	157	6	12·1	5·5	151	2	4·0	2·9
Deccani	168	10	14·4	5·7	158	3	5·0	2·9
Breed of dam								
Bannur	187	19	18·5	5·0	168	4	5·8	2·7
Deccani	283	12	11·7	4·8	271	6	4·6	2·5
Significance			**					

† Number of lambs.

Breed of dam and duration of dam at NARI effects. The breed of dam effect was significant for BWT, WT3, WOOL1 and MORT0-3 (all $P < 0{\cdot}01$) and also for ADG3 and WT6 ($P < 0{\cdot}05$). Lambs born to D dams were slightly heavier and had higher fleece weights than lambs born to B dams (Tables 3 and 4). Mortality among lambs of B dams from birth to 3 months was 18·5% compared with 11·7% among lambs of D dams ($P < 0{\cdot}01$). Effects of duration of dam at NARI were highly significant ($P < 0{\cdot}001$) for all weight and growth traits analysed but not for WOOL1, MORT0-3 or MORT3–6.

The weight of 3-month-old lamb produced per D ewe (13·2 (s.e. 0·7) kg) was significantly higher than that produced per B ewe (11·6 (s.e. 0·9) kg).

Other fixed effects and interactions. Year of birth had a significant ($P < 0{\cdot}001$) effect on all weight and growth traits and WOOL1 but not on MORT0-3 or MORT3–6. Male lambs were significantly heavier than females by 0·11 to 0·13 from birth to 6 months. The sex effect was not significant for WOOL1 or lamb mortality. Out of the total of 396 lambs with weight records up to 3 months, 19 were twin-born. Type of birth had a large and significant effect on all weight and growth traits analysed and WOOL1 and MORT0–3. Singles were heavier than twins by proportionately 0·47 at birth, 0·40 at 3 months and 0·19 at 6 months. Single lambs had proportionately higher fleece weights than twins and lower mortality (0·083 *v.* 0·220 from birth to 3 months). However, type of birth was not significant for MORT3-6 (0·038 among singles and 0·065 among twins). The weight of 3-month-old lamb produced per ewe was 4·95 (s.e. 1·15) kg higher for ewes bearing twin lambs compared with those bearing single lambs ($P < 0{\cdot}001$); despite the higher mortality among twins compared with singles.

After preliminary analyses, it was found best to split dam parities into three categories, first, second and third or greater. The parity of dam effect was significant for all traits analysed except WOOL1 and MORT0–3. Weights of lambs of second parity dams were significantly higher than lambs of maiden dams. MORT3-6 among lambs of primiparous dams was significantly higher (0·101, $P < 0{\cdot}01$) than lambs of multiparous dams (0·022 and 0·032 for lambs of second parity dams and third and higher parity dams respectively). First order interactions among the fixed effects were not significant for weight and growth traits and lamb mortality.

Resistance to GI nematodes of lambs (*FEC and PCV*)
Monthly species differentiation of larvae hatched from faeces of naturally infected lambs ≥ 3 months of age and reared at NARI from 1997 to 1999 indicated that for most of the year *H. contortus* was the predominant species (80 to 98%) with *Trichostrongylus colubriformis* making up the remaining 2 to 20%. However, from February to June 1997 and in May 1998, the proportion of *T. colubriformis* was found to be 32 to 47%. Sometimes *Oesophagostomum spp.* larvae were also found to comprise 1 to 6% of the composition.

Back-transformed least-squares means of cube-root transformed NATFEC for breed of sire and breed of dam effects, of one of the NATFEC measurements

Table 7 *Faecal egg counts† after natural challenge* (*NATFEC*) *and artificial challenge* (*ARTFEC*) *with* H. contortus *larvae‡*

	Natural challenge		Artificial challenge		
				ARTFEC (e. p. g.)	
	No. §	NATFEC (e. p. g.)	No. §	21 days post infection	26 days post infection
Breed of sire					
Garole	75	1661	65	1680	27837
Bannur	105	2113	91	2869	32037
Deccani	87	2603	80	4293	39275
Significance		**		**	**
Breed of dam					
Bannur	113	1849	94	2327	31985
Deccani	154	2377	142	3363	33686
Significance		*		*	*

† Back-transformed least-squares means of cube-root transformed faecal egg counts.
‡ NATFEC : lambs born in 1996, 1998 and 1999 (results from one measurement where faecal egg count was high). ARTFEC: lambs born in 1997, 1998 and 1999.
§ No. = number of lambs.

Table 8 *Least-squares means and standard errors of packed cell volume (PCV,%) of lambs born in 1998 and 1999, before artificial challenge with* H. contortus *larvae(Normal PCV), PCV decline at 15 and 27 days post infection (PCVD15 and PCVD27) and PCV (%) 27 days post infection*

		Normal PCV		Decline				PCV 27 days post infection	
				PCVD15		PCVD27			
	No. †	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Breed of sire									
Garole	54	29·6	0·7	3·7	0·8	6·5	0·8	23·2	0·8
Bannur	75	29·8	0·7	4·3	0·7	7·1	0·7	22·6	0·9
Deccani	62	28·6	0·7	3·5	0·7	7·5	0·7	21·1	0·9
Year of birth									
1998	110	27·9	0·6	0·1	0·6	1·8	0·6	26·1	0·6
1999	81	30·8	0·6	7·5	0·7	12·2	0·7	18·5	0·7
Significance		**		***		***		***	

† No. = number of animals.

where FEC was high and both 21- and 26-day post-infection measurements of ARTFEC are presented in Table 7.

Breed of sire and sire effects. The breed of sire effect was significant ($P < 0{\cdot}01$) for both NATFEC and ARTFEC. The ranking of breeds of sire for NATFEC was G < B < D and the differences were significant. With artificial challenge, lambs of G sires had the lowest mean FEC, followed by lambs of B sires, while the lambs of D sires had the highest mean FEC. The difference between G-sired and D-sired lambs was significant ($P < 0{\cdot}01$) and ARTFEC of D-sired lambs (4293 and 39275 e.p.g. at 21 and 26 days post infection, respectively) was 1·4 to 2·6 times that of G-sired lambs (1680 and 27837 e.p.g.). The interaction between breed of sire and year of birth was not significant. Sire variance was extremely low for NATFEC. The estimated heritability of $FEC^{0.33}$ after artificial challenge was 0·36 (s.e. 0·22) and the repeatability was estimated to be 0·49 (s.e. 0·06).

The breed of sire effect was not significant for any of the PCV variables analysed (Table 8). The sire within breed effect was significant only for PCV at 27 days post infection and the estimated heritability was 0·46 (s.e. 0·25).

Breed of dam effects. Breed of dam was significant ($P < 0{\cdot}05$) both for NATFEC and ARTFEC. Back-transformed least-squares mean NATFEC and ARTFEC of lambs of Bannur dams were less than lambs of Deccani dams (Table 7).

Other fixed effects and interactions. The effect of year of birth was highly significant ($P < 0{\cdot}001$) for NATFEC, ARTFEC and all the PCV variables. The effects of sex, type of birth and parity group of dam were not

Table 9 *Summary of characteristics of the Deccani (D), Bannur (B) and Garole (G) breeds†*

	Deccani (D)	Bannur (B)	Garole (G)
State of origin in India	Maharashtra	Karnataka	West Bengal
Climate adapted to	Hot, dry, semi-arid (S)	Hot, dry, semi-arid (S)	Hot, humid, swampy
Most important output	Lamb production	Lamb production	Lamb production
Ewe mature live weight (kg)	26·6	23·0	15·6
Average litter size	1·04	1·01	1·74 (S)
Relative lamb growth rates	High (S)	Medium	Low
Relative degree of resistance to GI nematodes	Low	Medium	High (S)
Annual frequency of shearing required	Twice	60% sheep do not require shearing; 40% require shearing once a year (S)	Twice
Hardiness in the Deccan plateau environment	Hardy (S)	Hardy (S)	Not hardy
Conformation	Rangy	Mutton type/stocky (S)	Rangy

† Characteristics which were considered to be particular strengths of each breed in this study are denoted with (S).

significant. The sex effect was probably not significant because all the male lambs were castrated. The effect of duration of dam at NARI was significant only for ARTFEC. The interaction between breed of sire and breed of dam and first-order interactions among the other fixed effects were not significant. Thus the ranking of breeds of sire for weight traits and FEC (G < B < D) remains the same irrespective of the breed of dam with which they are bred. The regression effect of age of lamb was not significant for FEC measurements.

Discussion

Adaptability

A summary of the important characteristics of the D, B and G breeds is given in Table 9. Increasing restrictions on the movement of animals from one country to another and cost considerations limit the choice of genotypes available to introduce a characteristic into a particular breed through crossbreeding. There were difficulties in the use of Garole ewes in this experiment because the humid environment they come from is very different from the semi-arid environment of the Deccan plateau. The higher mortality of G-sired lambs in this study could be due to the G breed not being adapted to a semi-arid environment. Baker *et al.* (2002) found much higher mortality (27%) in Dorper sheep bred for an arid environment, when they were reared in a coastal humid environment, compared with 5% mortality in Red Maasai sheep adapted to humid conditions. The overall efficiency of G-crossbred ewes is, however, likely to be greater than D or B ewes because of their higher prolificacy.

Genetic variation

The heritability of BWT was close to zero (0·03 (s.e. 0·08)) and the heritability of WT3, (0·15 (s.e. 0·12)), had a large standard error. However, the heritabilities of WT6 (0·39 (s.e. 0·22)) and $FEC^{0·33}$ after artificial challenge (0·36 (s.e. 0·22)) were considerably higher, indicating that within breed selection is likely to be a viable alternative to crossbreeding for improving lamb growth rates and resistance to GI nematodes. Logistical factors and costs involved in designing and implementing a successful long-term selection programme, however, need careful consideration. There are no examples of such selection programmes in sheep in India. If reproductive rate is to be raised by selection, there is limited scope for initial screening of D ewes for twinning because of the rare occurrence (2%) of prolific D ewes. The heritability estimates derived in this study were lower than the weighted average of heritabilities of different weight traits reported by Arora (1981), for the north Indian sheep breeds Chokla, Nali, Bikaneri, Marwari, Patanwadi and crosses of Nali and Lohi with Nellore and Mandya (Bannur) which were 0·15 for birth weight, 0·26 for weaning/3-month weight and 0·43 for 6-month weight. Estimates of heritability in D sheep reported by Kulkarni and Deshpande (1986) are, $0·68 \pm 0·02$ and $0·13 \pm 0·03$ for birth weight and $0·29 \pm 0·03$ and $0·30 \pm 0·04$ for 6-month weight in male and female lambs respectively.

Live weight. The average live weights of adult ewes in the NARI flock are 26·6 kg for Deccani, 23·0 kg for Bannur and 15·6 kg for Garole ewes respectively. The adult live weight of the Garole female has been reported elsewhere to be 14·1 kg (Sharma et al., 1999) and 14·3 kg (Banerjee and Banerjee, 2000).

Lambs sired by G rams (i.e. lambs with 50% G genes) in this study were significantly lighter at birth, 3 months and 6 months of age. Crossing the D with G leads to a substantial reduction in weight and growth rate as compared with D lambs. This difference is carried on into adulthood. This is demonstrated by the live weights of adult ewes of 6 genotypes born from 1996 to 1998 in the NARI flock. The mean live weight of 15 Deccani ewes was the highest at 26·9 kg, followed by 15 D × B and 32 B × D ewes with the same mean live weight of 24·8 kg, 15 Bannur ewes (24·4 kg), 18 G × D ewes (20·8 kg) and 10 G × B ewes (18·8 kg) ($P < 0·01$ since $F > F_{5, 99}$).

In contrast to this situation where crossing with the prolific but small G breed leads to a reduction in weights and growth rates, in Morocco, crosses between the prolific D'Man and the major national local breed Timahdit of low prolificacy, had similar or greater growth rates than purebred Timahdit lambs (El Fadili *et al.*, 2000).

Lamb mortality. Mortality in this experiment was higher compared with the pre-weaning mortality of 2·7 percent among Deccani lambs at the All India Coordinated Research Project on Sheep Breeding (Mutton) at the Mahatma Phule Agricultural University (Narwade et al., 1999). Mukasa-Mugerwa et al. (2000) reported a much higher mortality of 19·1 percent and 48·9 percent up to 6 months among indigenous Menz and Horro lambs, respectively, in Ethiopia.

Resistance to gastro-intestinal nematodes. Control of parasitic gastroenteritis is primarily based on the frequent use of anthelmintics at short intervals, particularly in intensive and semi-intensive management systems (Sanyal, 1996). Frequent suppressive dosing has been shown to result in the emergence of anthelmintic resistance (Overend *et al.*, 1994). Use of anthelmintics has spread widely in

India and there are reports of development of anthelmintic resistance (Singh *et al.*, 1995; Yadav *et al.*, 1995). In this context, genetically resistant breeds that require less frequent drenching are important (Baker, 1998). A few studies in India have assessed genetic variation in resistance to GI nematode parasites by comparing Indian sheep breeds with exotics and crosses of the two. The Indian sheep breeds Malpura and Nali were found to have lower FEC compared with their crosses with Rambouillet and Russian Merino or Corriedale respectively, suggesting higher resistance to *H. contortus* among the native breeds (Pachalag *et al.*, 1972; Singh *et al.*, 1996). However, there are no other studies comparing the level of resistance to GI nematodes of different indigenous Indian sheep breeds.

G-sired lambs were significantly more resistant than D-sired lambs to natural infection with GI nematodes as well as to an artificial challenge with *H. contortus*, as evident from their significantly lower FEC post infection. B-sired lambs appear to have nematode-resistance characteristics intermediate between the G-sired and D-sired lambs. This is consistent with the results of the repeated measures analysis of natural and artificial-challenge FEC for the first 2 years of this study reported by Nimbkar *et al.* (2000).

The finding of superior genetic resistance to *H. contortus* of the G and B breeds compared with the local D breed is important considering the widespread and increasing resistance to anthelmintics among worms in countries in many parts of the world as well as on some institutional farms in India. Other sheep breeds identified to be relatively resistant to gastro-intestinal nematodes are the East African Red Maasai, the Florida Native, the Barbados Blackbelly, the St Croix (Baker, 1996) and the Indonesian Thin Tail sheep (Subandriyo *et al.*, 1996).

Although for almost half the year the environment of the Deccan plateau is not prone to GI nematodes, recent studies (Ghalsasi *et al.*, 2002) have shown that even in years with average or below average rainfall, mean FEC in untreated sheep was 1200 e.p.g., averaged over the year, with a range in individual FEC of 0 to 20 000 e.p.g. Ghalsasi *et al.* (2002) also report that subclinical gastro-intestinal nematode infections in Deccani sheep cause significant production losses to the extent of 22·2% and a tactical drenching programme at the conservative intervention level of 500 e.p.g., which is similar to the shepherds' current practice had limited impact in ameliorating this production loss. Superior genetic resistance to GI nemotodes is therefore likely to have a substantial impact on the production of D sheep.

Fleece weight. The reduction in fleece weight after crossing the D with the B breed (11 to 22%) was not significant. Unlike the F1 crosses of Barbados Blackbelly, a hair sheep breed, with Sumatra sheep, which by the age of 9 months had very much less wool than other groups (Gatenby *et al.*, 1997), F1 crosses between the D and B would still have to be shorn every 6 months. The proportion of B genes that will reduce the frequency of shearing, needs to be investigated. The advantage of not having to shear, with the consequent advantages of elimination of shearing stress has to be balanced against the disadvantages of the B breed such as lower growth rates and body weights than D. According to Arora and Acharya (1976), B is superior to other Indian breeds in dressing percentage, carcass conformation and meat quality but has little or no advantage in growth, survival and reproductive performance. Local shepherds of the Deccan plateau usually sell all male lambs at 3 to 5 months while retaining most female lambs for further breeding. Sale prices of lambs depend mainly on a visual assessment of live weight and there is not much premium for meat conformation or meat quality. The contribution the B breed will make to a more efficient composite has to be determined in the light of these factors.

Benefits of twinning

The progressive reduction with increasing age of lamb, of the difference in weight between single and twin lambs, supports the greater profitability of a ewe bearing and rearing twins over one bearing a single. The significantly higher weight of 3-month-old lamb produced per ewe by twin-bearing ewes also indicates the higher productivity of ewes with twin lambs. In a crossbreeding trial conducted in Egypt to improve the prolificacy of the local Ossimi and Rahmani breeds by crossbreeding with Finnsheep, the number of lambs weaned per ewe per year increased by 0·2 with 25% genes from the exotic breed (Aboul-Naga, 2000).

FecB (*Booroola*) *gene*

Breeding studies at NARI supported the hypothesis that prolificacy in the Garole is due to a single major gene and this gene has been confirmed to be identical to the Booroola (*FecB*) mutation (Davis *et al.*, 2002). A direct Booroola PCR-RFLP test has been developed and described (Wilson *et al.*, 2001). This has opened up the possibility of introducing the trait of prolificacy into the Deccani breed or a composite by introgressing the Booroola gene. The B allele of the *FecB* (Booroola) gene was introduced into the Awassi and Assaf breeds using a marker-assisted selection approach and the use of induced ovulation rate as selection criteria, with a resultant increase in lambs born per ewe lambing-from 1·2 and 1·6 respectively to 2·0 (Gootwine *et al.,* 2001). However, there may be a need for structured matings in a programme of dissemination of the *FecB* gene.

The strategy to introduce the prolificacy of the G breed into another breed or composite will have to be devised so that the reduction in body weights and growth rates is minimized but the advantage of the Garole's nematode resistance genes is retained. The disadvantages of low weights and growth rates in a semi-arid environment that can be attributed to the G breed also have to be weighed against the advantage of its superior resistance to *H. contortus* compared with the D breed.

Conclusion

The growth performance, mortality and resistance to GI nematodes of crosses of D and B ewes with G, D and B rams have been evaluated. The significant effects of breed of sire and breed of dam on lamb weight and growth were largely because of the differences in mature size of the three breeds involved in the experiment, with lambs by D sires, the breed with the greatest mature size, being the heaviest. Crossing of D with G leads to a reduction in growth rate but improves resistance to *H. contortus*. Crossing of D with B also reduces growth rate and fleece weight but improves resistance to *H. contortus.* The superior resistance to gastro-intestinal parasites (predominantly *H. contortus*) of G-sired lambs compared with D-sired lambs, is an important finding of this study, especially in view of the increasing problem of anthelmintic resistance all over the world.

The final aim of the NARI crossbreeding programme is to increase the efficiency of sheep production on the Deccan plateau. Improving the reproductive performance of ewes is an established way to improve the efficiency of sheep reared for meat production. The maternal performance of the various crosses generated under the above programme and other crosses generated since is being evaluated. An overall definition of economic value will be determined to decide the comparative economic advantages of improvements in the reproductive potential and worm-resistance *vis-à-vis* the disadvantages of reduction in growth rate and live weight. The finding of the single gene inheritance of prolificacy due to the *FecB* (Booroola) gene in the G breed and the possibility of using DNA technology to introgress the Booroola gene into the proposed composite have made another alternative available. However, the management implications of an increase in fecundity have to be considered. Acceptability of the final genotype to the local shepherds is by far the most important consideration.

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