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Comparative intensity of infection and performance of lambs selected for resistance or susceptibility to *Haemonchus contortus* in semi-arid Rajasthan

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ABSTRACT

The present study aimed to determine the variation in intensity of strongyle infection and performance in lambs of three divergent lines (selected for resistance or susceptibility to *Haemonchus contortus* and unselected) in semi-arid Rajasthan. From the year 2004 to 2014, a total of 13,515 faecal samples from lambs (5–6 month of age) naturally infected with gastrointestinal nematodes (GINs) were evaluated for intensity of strongyle infection and estimated pasture contamination rate by them. The monthly mean intensity of strongyle infection remained significantly higher in susceptible line compared to other lines. In the month of peak parasitism (September), minimum proportion (34.54–45.61%) of animals possess higher FEC in resistant lambs followed by unselected (44.32–50.50%) and maximum (53.58–56.27%) by susceptible lambs. In majority of months, resistant lambs had lower contamination rate (>30%) compared to susceptible lambs. The magnitude of average daily gain (ADG) in body weight exhibited significant variation among different lines only between 6–9 months of age in Malpura (31.1±1.2 g/day in unselected line to 38.5±2.3 g/day in resistant line) and Avikalin breed (27.1±1.8 g/day in unselected line to 35.6±1.7 g/day in resistant line). During peak wormy season, a significant and negative correlation was found between FEC and weight at 6 and 9 month of age in susceptible line only. The study suggested that management of gastrointestinal nematodosis in flock through selection of sheep for resistance to strongyle worms led to decreased pasture contamination, lower intensity of infection with better performance in resistant flock.

Key words: Average daily weight gain, *Haemonchus contortus*, Pasture contamination, Rajasthan, Semi-arid, Sheep

In sheep farming, gastrointestinal nematodes (GINs) were found to impose massive economic loss worldwide (Singh *et al*. 2011, Bentounsi *et al*. 2012). Control of GINs is mainly accomplished by administering anthelmintics irrespective of epidemiological knowledge (Kenyon and Jackson 2012, Valcarcel *et al*. 2013). The sole dependence on anthelmintics found to impose higher pressure for selection of anthelmintic resistance in worm population (Swarnkar and Singh 2012). Efficient worm control is possible through the integration of several methods, such as grazing management, nutritional supplementation, the strategic use of anthelmintics, vaccines and predatory fungi, as well as breeding for resistance, all contained in a protection program (CSIRO 2007). The selection of sheep, particularly growing lambs, with enhanced resistance to GINs is often advocated as a control measure that may complement other strategies. There is now considerable evidence for genetic variation in resistance to parasites both within and between breeds of animals (Bishop 2012).

Resistance to internal parasites varies considerably between animals and 20–30% of this variation is due to genetic differences between animals (Nimbkar *et al*. 2003, Yadav *et al*. 2006). The largest source of genetic variation in resistance is within flock rather than between flocks (Kumar *et al*. 2006). Resistance of individual hosts is expected to reduce incidence and intensity of infection in flock with reduced parasite transmission in the population (Klasing 2004, Graham *et al*. 2005). In a flock, the immune response is not uniform in the animals and most of the host carry few parasites; while a few heavily infected hosts harbour majority of parasite population i.e. over-dispersed distribution (Singh *et al*. 2015). The use of genetically resistant host has a great influence on worm epidemiology with reduced pasture larval burden due to low intensity of infection during peak parasitic season in genetically resistant sheep (Bishop and Stear 1999). On meta-analysis, Mavrot *et al.* (2015) indicated lower weight gain in infected animals (77% compared to parasite-free animal). In Brazil, under natural infection, Lobo *et al.* (2009) observed that selection to increase resistance will not adversely affect lamb growth, although lambs with a slow growth rate may be more susceptible to infection. Further, the use of genetically resistant hosts permits a reduced anthelmintics treatment leading to delay in anthelmintic resistance as well as

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maintain or increase *refugia*. A study was conducted with the aim to determine the variation in intensity of strongyle infection and growth performance in lambs of divergent lines (w.r.t. resistance to GINs) during their first grazing season in semi-arid Rajasthan.

MATERIALS AND METHODS

Study area: The study was carried out at the ICAR-Central Sheep and Wool Research Institute, Avikanagar, located in the hot semi-arid region of India, 75°282 E latitude and 26°172 N longitude at an altitude of 320 m above mean sea level. The soil is sandy and the vegetation is composed of natural pasture, bushes and trees. Temperature varies over the year from 4°C to 46°C with average annual rainfall around 500 mm. All the sheep were raised under semi-intensive management system and provided similar grazing/feeding conditions.

Animals: All the lambs (5–6 month of age) of native Malpura and crossbred Avikalin (Rambouillet × Malpura), born during spring season were used to assess the intensity of strongyle infection and growth response while grazing on naturally contaminated pasture. In addition to grazing, concentrate mixture was offered *ad lib.* to lambs from 15 days age until weaning (90 days). After about 3 weeks of age, lambs were sent for grazing in morning and evening. During post-weaning period in addition to 8–10 h grazing and dry fodder supplementation, 300 g concentrate mixture was provided. Prophylactic health measures against ET, PPR and Sheep Pox were practiced as per planned flock health approach.

Observations: The lambs were divided in to three groups as per divergent lines, viz. resistant or susceptible to GINs (predominantly *Haemonchus contortus*) and unselected. The protocol for selection of lambs in divergent lines was described elsewhere (Swarnkar *et al*. 2009). Each year per rectum individual faecal samples were collected from (~90% of available lambs) July to November at monthly interval. From the year 2004 to 2014, a total of 13,515 faecal sample (8,154 from Malpura and 5,361 from Avikalin breed) were collected and evaluated for intensity of strongyle infection (faecal egg count – FEC) through modified Mc Master technique (MAFF 1986). Meanwhile every year, primary infection was terminated by anthelmintic (levamisole or closantel) drench in the month of September. The frequency distribution of lambs was made by grouping the lambs in to four groups based on monthly FEC as Gr-1, nil epg; Gr–2, 100–500 epg; Gr-3, 501–2000 epg and Gr-4, >2000 epg. The rate of pasture contamination by lamb of each line was determined as under:

$$\text{Pasture contamination rate (per lamb/g faeces)} = \sum_{(Gr1\text{-}4)} (\text{Mean monthly FEC} \times \text{Proportion of lambs})/100$$

The assessment of efficacy of different divergent lines in pasture contamination rate was determined by comparing the pasture contamination rate between lines. The data on growth performance were taken as body weight at 6, 9 and 12 month of age and expressed as average daily gain (ADG) in body weight during the age between 6–9 month (ADG1) and 9–12 month (ADG2). In addition, greasy fleece weight (GFW) at first six month of age was also recorded. The data were subjected to analysis of variance and means were compared by Duncun's multiple range test and calculated Pearson correlation coefficient for interaction study using SPSS ver 20.0.

RESULTS AND DISCUSSION

Intensity of strongyle infection: Irrespective of sex of animal, the monthly mean FECs remained significantly higher in susceptible line (29.5±7.0 epg in July to 3939.7±227.1 epg in September) compared to other lines in Malpura breed. On the other hand, lambs from resistant sires exhibited significantly lower FEC on all the occasion compared to other lines (Table 1). An almost similar trend was observed in Avikalin breed. In both the breeds, male had non-significantly higher FECs on almost all occasions.

Frequency distribution of lambs as per level of strongyle infection: In all the three divergent lines, majority of lambs (87–94%) exhibited absence of strongyle infection in the month of July and 5–12% possessed low intensity (100–500 epg) of infection. With the return of favourable conditions for translation of exogenous stages of *H. contortus* (Swarnkar and Singh 2011, 2013) in the month of late July, the proportion of lambs positive for strongyle infection increased to 49–57% in August with relatively higher proportion possessing FEC from 100–500 epg in all the lines of Malpura breed. However, in Avikalin breed, FEC of >2,000 epg was observed in relatively higher proportion of lambs of susceptible and unselected line. In the month of peak parasitism (September), maximum proportion (34.54 to 56.27%) of lambs possessed FEC to tune of >2,000 epg. In both the breeds, minimum proportion (34.54–45.61%) of animals possessed higher FEC in lambs from resistant line followed by unselected line (44.32–50.50%) and maximum by susceptible line (53.58–56.27%). Between breed comparison exhibited higher proportion of lambs with >2,000 epg in Avikalin than Malpura breed in all the divergent lines (Table 2).

Following termination of primary infection in the month of September and subsequent grazing on naturally contaminated pasture, it was found that in October, 30.38–30.93% of lambs in resistant line had no infection compared to 16.10–23.79% in other line from both the breeds. Almost similar trend with lower magnitude was observed in the month of November. In both the breeds, the proportion of lambs possessing >2,000 epg was minimum in resistant line during October-November followed by unselected line and maximum in susceptible line.

Pasture contamination rate (per lamb/g faeces) by lambs: Among three lines of lambs, average monthly FECs were lowest (12.2 epg in July to 2,348.1 epg in September) in resistant line in Malpura (Table 1). Similarly trend was observed in Avikalin (25.1 epg in July to 3,559.9 epg in September) except in the month of July and September where FECs were lowest in lambs of unselected line (Table 1). On the contrary, the lambs of susceptible line

Table 1. Monthly mean (±SE) faecal egg count (egg/g of faeces) in different lines of sheep

Line and Sex	FEC/g of faeces				
	July	August	September	October	November
			Malpura		
Resistant	12.2±2.6[a] (427)	885.9±91.7 (447)	2348.1±162.6[a] (414)	628.5±74.1[a] (375)	647.8±55.3[a] (406)
Male	13.8±4.0 (217)	1018.1±139.8 (221)	2544.5±251.1 (205)	722.9±83.0 (191)	697.5±71.0 (195)
Female	10.5±3.3 (210)	756.6±118.9 (226)	2155.5±207.3 (209)	530.4±123.8 (184)	601.9±83.7 (211)
Unselected	24.5±4.5[ab] (771)	886.8±69.6 (770)	3289.7±178.5[b] (740)	670.8±46.8[a] (618)	934.9±63.8[b] (717)
Male	36.6±8.4 (388)	990.6±106.2 (382)	3446.9±236.6 (354)	681.9±54.6 (293)	817.4±63.1 (339)
Female	12.3±2.7 (383)	784.5±90.0 (388)	3145.6±264.8 (386)	660.7±74.2 (325)	1040.2±106.8 (378)
Susceptible	29.5±7.0[b] (519)	922.0±86.5 (519)	3939.7±227.1[c] (489)	969.8±75.5[b] (471)	943.3±75.5[b] (471)
Male	30.4±6.8 (253)	1024.1±133.5 (257)	3977.1±330.9 (238)	907.8±120.6 (193)	1001.7±89.4 (295)
Female	28.6±12.0 (266)	821.8±110.3 (262)	3904.3±312.7 (251)	1023.2±141.7 (224)	887.6±120.4 (299)
P value	0.090	0.941	0.001	0.001	0.004
			Avikalin		
Resistant	25.1±4.5[ab] (411)	890.7±86.1[a] (429)	3559.9±225.8[a] (421)	800.0±80.4[a] (372)	677.0±51.2[a] (413)
Male	23.4±7.4 (205)	1091.3±138.0 (207)	3753.1±324.2 (198)	897.7±139.5 (177)	823.8±81.1 (193)
Female	26.7±5.2 (206)	703.7±101.1 (222)	3388.3±314.6 (223)	711.3±86.5 (195)	548.2±63.4 (220)
Unselected	10.8±5.1[a] (287)	1349.0±142.2[b] (317)	3532.1±235.2[a] (299)	1028.0±85.3[ab] (236)	1098.6±102.5[b] (292)
Male	15.8±9.2 (158)	1400.6±189.6 (179)	3267.1±284.9 (170)	1068.2±125.1 (132)	1146.7±105.7 (167)
Female	4.7±1.9 (129)	1282.0±215.6 (138)	3881.4±394.5 (129)	976.9±111.1 (104)	1034.4±193.8 (125)
Susceptible	30.3±6.4[b] (366)	1572.7±166.4[b] (388)	4385.6±257.5[b] (391)	1190.0±103.4[b] (350)	1165.6±89.3[b] (387)
Male	27.8±6.9 (187)	1745.1±254.1 (202)	4220.8±306.0 (202)	1557.1±182.7 (168)	1374.6±135.1 (197)
Female	33.0±10.9 (179)	1385.5±210.6 (186)	4561.7±421.1 (189)	851.1±199.6 (182)	949.0±114.3 (190)
P value	0.046	0.001	0.017	0.006	0.001

Means with similar superscript differ non-significantly among lines with in month; Figures in parenthesis indicates number of observations

exhibited highest monthly FECs in both the breeds. In Malpura breed, magnitude of pasture contamination rate by a lamb revealed that in comparison to susceptible lamb, resistant lamb had lower contamination rate with a magnitude of >30% in all the months except in August (3.91%). Similar pattern (except in October) was observed on comparison of resistant and unselected line. Lamb of unselected line also had lower contamination rate (0.90% in November to 38.83% in October) compared to susceptible line (Table 3). In Avikalin breed, resistant lamb had lower contamination rate (from 17.16% in July to 43.36% in August) compared to susceptible lamb. Similar pattern of lower magnitude (except in July) was observed on comparison of resistant and unselected line. Lamb of unselected line also had lower contamination rate compared to susceptible line in all the months.

Breeding sheep resistant to infection with GINs is widely promoted as a management option for the control of worms. Selective breeding of lambs reduces faecal worm egg count with substantial reduction in density of infective larvae on pasture (Klasing 2004, Graham *et al*. 2005) and a reduced reliance on anthelmintic control (Besier and Love 2003). Faecal worm egg counts remain the most effective way of selecting sheep for parasite resistance (Gray 1997). The ability of sheep to acquire immunity and express resistance varies between and within breeds and is under genetic control (Stear and Murray 1994). Similar to present findings, significant (P<0.001) variations in monthly FECs (particularly during wormy season: Aug- Nov) among resistant and susceptible lines were reported by Swarnkar *et al.* (2009) in Malpura and by Prince *et al.* (2010) in Avikalin breed.

Growth performance and first six monthly greasy fleece weight (GFW) of lambs: Irrespective of sex, there was non-significant variation in mean body weights at 6, 9 and 12 month of age of lambs in all the three lines of Malpura breed (Table 4). However, in Avikalin breed, significantly (P<0.001) lower body weights were recorded in lambs of unselected line at all the stages compared to resistant and susceptible lines. The magnitude of ADG at different stages of growth exhibited significant (P<0.004) variation among different line only between 6–9 months of age in Malpura breed (31.1±1.2 g/day in unselected line to 38.5±2.3 g/day in resistant line). Like-wise in Avikalin breed, ADG remained significantly (P<0.003) higher at 6–9 months of age in resistant line (35.6±1.7 g/day) compared to other lines (27.1±1.8 and 31.5±1.6 g/day). A nonsignificant variation in mean first 6–monthly GFW was observed among all the divergent lines in both the breeds (Table 5). Vanimisetti *et al.* (2004) reported no consistent relationships with body weight. The association between body weight and strongyle FEC thus varied substantially among individuals (Hayward *et al*. 2014). The present findings suggested that natural challenge of lambs occurs from 6

Table 2. Frequency distribution (%) of lambs as per monthly level of strongyle infection

Month	Malpura				Avikalin			
	Nil	100-500	501-2000	>2001	Nil	100-500	501-2000	>2001
				Resistant				
Jul	92.97 (397)	6.79 (29)	0.23 (1)	0.00 (0)	87.35 (359)	12.17 (50)	0.49 (2)	0.00 (0)
Aug	51.23 (229)	20.81 (93)	14.54 (65)	13.42 (60)	48.02 (206)	21.21 (91)	15.62 (67)	15.15 (65)
Sep	12.32 (51)	23.91 (99)	29.23 (121)	34.54 (143)	4.51 (19)	21.85 (92)	28.03 (118)	45.61 (192)
Oct	30.93 (116)	48.40 (144)	24.00 (90)	6.67 (25)	30.38 (113)	34.68 (129)	22.58 (84)	12.37 (46)
Nov	25.12 (102)	45.32 (184)	21.18 (86)	8.37 (34)	18.64 (77)	46.97 (194)	26.39 (109)	7.99 (33)
				Susceptible				
Jul	88.82 (461)	43.31 (204)	0.96 (5)	0.19 (1)	87.98 (322)	10.66 (39)	1.37 (5)	0.00 (0)
Aug	49.33 (256)	19.85 (103)	15.99 (83)	14.84 (77)	42.78 (166)	19.07 (74)	16.75 (65)	21.39 (83)
Sep	9.20 (45)	15.75 (77)	21.47 (105)	53.58 (262)	5.12 (20)	15.60 (61)	23.02 (90)	56.27 (220)
Oct	22.30 (93)	10.02 (52)	33.50 (98)	12.47 (52)	19.43 (68)	34.29 (120)	28.86 (101)	17.43 (61)
Nov	16.56 (78)	41.73 (174)	28.03 (132)	12.10 (57)	12.66 (49)	40.05 (155)	28.68 (111)	18.60 (72)
				Unselected				
Jul	89.75 (692)	9.73 (75)	0.39 (3)	0.13 (1)	94.43 (271)	5.23 (15)	0.35 (1)	0.00 (0)
Aug	47.79 (368)	22.47 (173)	16.23 (125)	13.51 (104)	49.84 (158)	12.62 (40)	15.77 (50)	21.77 (69)
Sep	14.73 (109)	16.76 (124)	24.19 (179)	44.32 (328)	3.01 (9)	19.06 (57)	27.42 (82)	50.50 (151)
Oct	23.79 (147)	42.23 (261)	26.86 (166)	7.12 (44)	16.10 (38)	29.66 (70)	38.56 (91)	15.68 (37)
Nov	16.46 (118)	46.44 (333)	24.83 (178)	12.27 (88)	8.56 (25)	39.38 (115)	37.33 (109)	14.73 (43)

Figures in parenthesis indicates number of observations.

Table 3. Average monthly variation (%) in pasture contamination rate by lambs of divergent lines

Month	Malpura			Avikalin		
	R over S	R over U	U over S	R over S	R over U	U over S
Jul	- 58.64	- 50.20	- 16.95	- 17.16	132.41	- 64.36
Aug	- 3.91	- 0.10	- 3.82	- 43.36	- 33.97	- 16.58
Sep	- 40.40	- 28.62	- 16.50	- 18.83	0.79	- 19.46
Oct	- 35.19	- 6.31	- 38.83	- 32.77	- 22.18	- 13.61
Nov	- 30.71	- 31.33	- 0.90	- 41.92	- 38.38	- 5.75

R, Resistant line; S, susceptible line; U, unselected line.

months of age onwards and deworming takes place at the age of 8 to 9 months as a set management practice in the flock. In Avikalin sheep, Prince *et al.* (2010) observed a significant (P<0.05) effect of FEC class for 6 and 9 month body weight and non-significant for 12 month weight. ADG from 9 to 12 months of age is not affected as a result of termination of infection before attaining annual weight. Body weight at 12 month of age is not affected by FEC class as a result of termination of infection before animals attain 12 month of age, as well as due to prevailing climate not suitable for translation and propogation of exogenous stages of *H. contortus* on pasture in this region (Swarnkar *et al*. 2008). In Santa Inκs breed, Lobo *et al.* (2009) observed an inverse relation between growth and FEC level after the first challenge, however during second challenge a considerable gain in body weight even after rise in FEC levels suggests an increase in parasite resistance with age. The negative association between strongyle nematode burden and body weight is likely to arise from parasite-induced anorexia and parasite- and immune-mediated damage to the intestinal wall (Gulland 1992). Hayward *et al.* (2014) reported a 13-fold more weight loss in less tolerant sheep (226 g/100 epg) than most tolerant sheep (18 g/100 epg). Mavrot *et al.* (2015) reported that by mixed species infection, an increase in FEC of 100, 1000 and 10000 epg resulted in the high parasite burden lambs gaining 0.85, 0.71 and 0.6 times the weight of the low parasite burden lambs, respectively.

The correlation between monthly intensity of strongyle infection and growth performance exhibited that in Malpura breed, during peak wormy season in the study area (September) and prior to drench a significant and negative correlation was found between FEC and weight at 6 and 9 (P<0.05) month of age in susceptible line only (Table 6). However, during the same month the correlation between FEC and the rate of ADG1 (6–9 months) remained nonsignificant but negative in susceptible and unselected line. After drenching relatively higher and negative but significant correlations were observed between FEC for November and body weight at 9 and 12 months of age in

Table 4. Mean (±SE) body weight and average daily weight gain at different stages of growth in lambs from different divergent lines of sheep

Line and sex	Body weight (kg)			Average weight gain (g/day)	
	6 month	9 month	12 month	6-9 months	9-12 months
			Malpura		
Resistant	21.73±0.21 (476)	25.08±0.26 (420)	28.78±0.32 (335)	38.5±2.3^{a} (420)	51.4±2.9 (335)
Male	23.23±0.32 (236)	27.06±0.41 (199)	31.54±0.56 (143)	42.2±3.8 (199)	60.3±5.1 (143)
Female	20.26±0.23 (240)	23.3±0.27 (221)	26.72±0.31 (192)	35.2±2.7 (221)	44.7±3.4 (192)
Unselected	21.74±0.15 (835)	24.68±0.19 (729)	29.07±0.24 (612)	31.1±1.2^{b} (729)	52.1±2.1 (612)
Male	23.28±0.22 (410)	26.67±0.29 (343)	31.96±0.36 (278)	34.3±2.0 (343)	63.5±3.6 (278)
Female	20.25±0.18 (425)	22.91±0.22 (386)	26.67±0.26 (334)	28.2±1.5 (386)	42.6±2.3 (334)
Susceptible	22.03±0.19 (562)	25.28±0.23 (479)	28.91±0.29 (391)	32.0±1.6^{b} (479)	48.7±2.7 (391)
Male	23.51±0.29 (275)	27.20±0.34 (238)	32.05±0.44 (178)	36.9±2.5 (238)	51.3±3.0 (178)
Female	20.61±0.22 (287)	23.40±0.27 (241)	26.29±0.28 (213)	27.1±1.9 (241)	46.5±4.2 (213)
P value	0.437	0.120	0.755	0.004	0.596
			Avikalin		
Resistant	22.88±0.22^{b} (460)	26.21±0.26^{b} (426)	29.81±0.34^{b} (368)	35.6±1.7^{b} (426)	43.7±2.3 (368)
Male	23.99±0.34 (222)	27.99±0.42 (194)	32.51±0.55 (153)	39.1±2.5 (194)	47.3±3.9 (153)
Female	21.84±0.27 (238)	24.73±0.29 (232)	27.90±0.38 (215)	32.7±2.4 (232)	41.0±2.8 (215)
Unselected	21.69±0.29^{a} (316)	24.20±0.32^{a} (292)	27.72±0.41^{a} (238)	27.1±1.9^{a} (292)	45.7±3.3 (238)
Male	22.86±0.42 (178)	25.61±0.45 (166)	30.37±0.60 (122)	30.2±2.9 (166)	56.9±5.2 (122)
Female	20.19±0.34 (138)	22.35±0.37 (126)	24.92±0.43 (116)	23.0±2.0 (126)	33.9±3.7 (116)
Susceptible	22.98±0.24^{b} (395)	25.93±0.29^{b} (395)	29.74±0.35^{b} (329)	31.5±1.6^{ab} (395)	46.0±2.4 (329)
Male	24.32±0.36 (217)	27.74±0.45 (202)	32.33±0.53 (158)	35.7±2.4 (202)	51.7±3.9 (158)
Female	21.54±0.27 (201)	24.04±0.32 (193)	27.34±0.39 (171)	27.0±1.9 (193)	40.8±2.7 (171)
P value	0.001	0.001	0.001	0.003	0.766

Means with similar superscript differ non-significantly among lines within month; Figures in parenthesis indicates number of observations.

Table 5. Mean (±SE) first six-monthly greasy fleece weight (kg) in lambs from different divergent lines of sheep

Breed	Resistant			Susceptible			Unselected		
	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
Malpura	0.66±0.03	0.59±0.01	0.62±0.01	0.65±0.01	0.61±0.01	0.63±0.01	0.64±0.01	0.59±0.01	0.62±0.01
(P=0.560)	(230)	(242)	(472)	(263)	(280)	(543)	(392)	(416)	(808)
Avikalin	0.95±0.02	0.82±0.02	0.88±0.02	0.97±0.02	0.81±0.02	0.89±0.01	0.98±0.03	0.84±0.03	0.92±0.02
(P=0.195)	(217)	(237)	(454)	(208)	(204)	(412)	(179)	(142)	(321)

Figures in parenthesis indicates number of observations.

resistant and unselected lines. In Avikalin breed, a significant and negative correlation was found between FEC for October and weight at 6 and 9 (P<0.05/0.01) month of age in susceptible and unselected line. The Pearson correlation coefficient between FEC for September and GFW was significantly (P<0.01) negative in susceptible Malpura line. In Avikalin breed, a significant (P<0.01) and positive correlation was found between FEC for September and GFW in resistant and unselected lines. On the contrary, a significant but negative correlation occurred between FEC for November and GFW in resistant and unselected lines.

The immune response against worm infection comes at a cost to production (Colditz 2008). Reported genetic correlations between FEC and growth rate in sheep vary from strongly favourable (Bishop *et al*. 1996), through moderately favourable or neutral (Eady *et al*. 1998) to moderately unfavourable (McEwan *et al*. 1995), with the majority of correlation estimates being negative. Selection for reduced FEC resulted in large correlated increases in live-weight gain more than twice that predicted by quantitative genetic theory, due to the reductions in growth rate losses as the disease challenge to the animals decreased (Amarante and Amarante 2003). Bishop *et al.* (1996) also estimated negative phenotypic correlations between FEC and live weight in Scottish Balckface lambs, but the values were close to zero. In Romney sheep, resistance has a negative genetic correlation with body weight and fleece weight (Wheeler *et al*. 2008). Under natural challenge, Lobo *et al.* (2009) reported the phenotypic correlation between transformed FEC with body weight as 0.04. Gauly and

Table 6. Pearson correlation coefficient between intensity of infection and growth/production traits in lambs

Month	Line	Body weight						Average daily weight gain				Greasy fleece weight	
		6 month		9 month		12 month		6-9 month		9-12 month			
		M	A	M	A	M	A	M	A	M	A	M	A
Jul	R	0.079	0.113*	0.135*	0.049	0.044	-0.082	0.072	-0.079	-0.106	-0.236**	0.032	-0.117*
	S	0.031	0.106*	0.041	0.082	0.007	-0.002	0.019	-0.066	-0.061	-0.181**	0.080	-0.033
	U	0.098*	0.033	0.085*	0.058	0.079	0.061	-0.001	0.043	0.002	0.046	0.056	0.016
Aug	R	-0.193**	-0.082	-0.300**	-0.117*	-0.179**	0.020	-0.231**	-0.123*	0.159**	0.131*	-0.079	-0.040
	S	-0.066	-0.106*	-0.137**	-0.157**	-0.074	-0.035	-0.118*	-0.210**	0.156**	0.219**	-0.023	-0.093
	U	-0.128**	0.167**	-0.226**	0.039	-0.149**	0.185**	-0.200**	-0.220**	0.076	0.326**	-0.018	0.082
Sep	R	0.001	0.013	0.016	-0.012	0.077	-0.026	0.029	-0.003	-0.065	-0.021	-0.013	0.134**
	S	-0.115*	-0.079	-0.107*	0.048	-0.041	0.047	-0.008	0.093	0.057	-0.049	-0.152**	0.028
	U	0.022	0.071	0.082*	0.050	0.080	-0.078	-0.028	-0.068	0.054	-0.225**	0.038	0.170**
Oct	R	-0.017	0.014	-0.053	-0.082	-0.013	0.013	-0.071	-0.094	0.052	0.071	0.022	0.015
	S	-0.060	-0.144**	-0.134*	-0.163**	-0.092	-0.050	-0.008	-0.083	0.150**	0.012	-0.048	0.004
	U	-0.010	-0.142*	-0.027	-0.222**	-0.014	-0.046	-0.019	-0.251**	0.070	0.200**	0.001	-0.057
Nov	R	-0.118*	-0.162**	-0.158**	-0.120*	-0.120*	0.022	-0.062	-0.011	0.016	0.084	-0.043	0.149**
	S	-0.050	-0.235**	-0.084	-0.237**	-0.097	-0.143*	-0.047	-0.082	0.039	0.020	0.020	-0.074
	U	-0.131**	-0.239**	-0.170**	-0.269**	-0.171**	-0.204**	-0.120**	-0.104	-0.041	0.031	0.012	-0.210**
			weight										

*,Significant (P<0.05); **, significant (P<0.001); M, Malpura; A, Avikalin; R, resistant line; S, susceptible line; U, unselected line.

Erhardt (2001) estimated a significant negative correlation for FEC and daily weight gain (r = -0.57) in Rhön sheep of Germany. The variation in correlation could be caused by different parasite species, different experimental conditions and protocols and/or the different genetic background of the animals. In Merino sheep, Kelly *et al.* (2013) reported that worm egg count was negatively correlated with live weight gain during infection but not with greasy fleece weight. The genetic and phenotypic relationships between log FEC and body weights of ewes were –0.26 and –0.06 for Muzaffarnagri sheep (Yadav *et al*. 2006). The live weight at any given age is a cumulative effect of all the experiences that the animal had up to that age, whereas a FEC simply describes the state of being at that point in time, for the current infection. Vanimisetti *et al.* (2004) reported an unfavourable relationship of resistance with fleece weight. Bishop and Stear (2003) summarized that genetic relationships between performance and resistance are the outcome of a complex set of factors. Although infection inevitably compromises performance, the ability of an animal to withstand infection or disease depends on the environment, particularly the protein nutrition available to the animal (Coop and Kyriazakis 2001). Consequently, genetic relationships between resistance and performance may be thought of as the outcome of a balance between two opposing factors: the resources used by the host to fight or protect the damage caused by infection. It was concluded that management of gastrointestinal nematodosis in flock through selection of sheep for resistance to strongyle worms lead to decreased pasture contamination, lower intensity of infection with higher body weight gain and wool yield in resistant flock.

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