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Genetic studies on growth and production traits in German Angora Rabbits under sub-temperate climatic conditions

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ABSTRACT

This study aimed to assess the effect of genetic and non-genetic factors on growth, wool yield and wool characteristics of German Angora rabbit. Data was collected on 607 adult rabbits over a period of four years (2018-2021). The least squares means of body weights (g) at various ages, wool yield (g) at I, II, III and IV clip and wool characteristics assessed by staple length (cm) and fiber diameter (μ) were estimated. Sires of the rabbit progenies demonstrated highly significant effect (P<0.01) on the studied traits except wool characteristics. Sex of the rabbits had significant effect on body weight at 10th, 12th, 14th, 16th, 24th weeks of ages and wool yield at III clip, with greater estimates of females than the males for III clip, staple length, and 24th weeks body weight. Winter and autumn seasons were the most favourable seasons in comparison to summer season for estimated traits. Winter born kits had the highest body weights of 683±20.1, 961±24.3, 1263±27.5, 1484±34.0, 1735±37.1, 1942±40.1, 2136±36.9, 2232±36.7, 2341±37.4 and 2429±37.4 g and the summer born kits had the lowest body weights of 588±22.0, 820±27.2, 1037±31.2, 1307±38.0, 1515.79±41.0, 1696±44.1, 1847±41.4, 1920±41.0, 2034±42.4 and 2139±41.6 g, at biweekly interval from 6th to 24th, respectively. Rabbits with litter size less than six performed better in comparison to other groups for all growth traits and wool yield at I and III clip. The heritability estimates were found positive and high in magnitude for all growth traits, moderate for wool clip at different clips and very low for staple length. Genetic and phenotypic correlations were found to be very high and significant among growth traits and low to moderate among wool traits. The study revealed scope for further improvement in growth and wool yield by adopting selective breeding in the colony.

Keywords: Correlation, German Angora rabbit, Growth traits, Heritability, Wool quality, Wool yield

German Angora rabbit is primarily reared for fine wool production, because of its high production potential and wool prices are generally 10-30 times more than that of sheep (Ossard *et al*. 1995). Besides, the angora fiber has a unique position among all animal-origin fibers due to its fineness, warmth, fluffiness, odorlessness, lightness and anti-static property to repel the dirt. It is much warmer (eight times) and lighter than sheep wool due to its hollow core (Pokharna *et al.* 2004) and is being used either in pure or blended form throughout the world for making garments. Hence, the profitability of Angora rabbit farming largely depends on its growth and wool production performance and appears to be affected by a number of genetic as well as non-genetic factors (Thebault *et al*. 1992, Niranjan *et al*. 2010, Sarma *et al.* 2020). The aid of selection tools largely depends on body weight, litter size at birth and weaning, wool yield and its quality. The selection of the traits changes the genetic structure of population by changing gene and genotypic frequencies and hence, the genetic parameters are also liable to change in the every generation (Falconer and Mackey 1996). The knowledge of genetic and phenotypic parameters is of paramount importance to formulate effective breeding plans for improving these economic traits through selection and breeding (Singh *et al.* 2008). The North Temperate Regional Station of ICAR-Central Sheep and Wool Research Institute, Garsa imported superior germplasm of German Angora rabbit from Germany in 1997. The population was well acclimatized to Himalayan terrain of Himachal Pradesh and is being maintained as closed flock at this Institute to improve the Angora rabbit fiber production. At present, this station has been recognized as germplasm center for pedigreed German Angora rabbits. Hence, the present investigation was undertaken to assess the genetic and non-genetic factors on body weights, wool yield and wool characteristics in pedigreed German Angora rabbit at this Institute farm.

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MATERIALS AND METHODS

Experimental animals, location sites and management practices: The German Angora rabbits maintained at the North Temperate Regional Station, ICAR-Central Sheep and Wool Research Institute, Garsa, Kullu were investigated for a period of four years (2018-2021) with the avowed intension of assessing various genetic and non-genetic factors on growth and production traits under sub-temperate climatic condition. The farm is located at an altitude of 1400-2100 meters above mean sea level at 31.28° North latitude and 77.20° East longitude. The climate is sub-temperate with temperatures ranging from -4°C to 35°C with average annual rainfall of about 840 mm mainly during the monsoon season. The Angora flock was maintained with optimum inputs under conventional intensive rearing system. The animals were housed in all-wire mesh cages of standard size with provisions of clean drinking water and feeding in the morning and evening. Animals were fed with concentrate feed (15 to 20% crude protein) in graded quantity from 90 to 220 g according to their age, body weight and physiological status. Seasonal grasses were provided *ad lib*. Approximately 40 to 60 breeding females were maintained annually with male to female ratio of 1:5. The rabbits were mated as and when they attained sexual maturity at 6 to 7 months of age. The female rabbit was brought to the male rabbit cage for mating and never vice versa. After successful mating, the male rabbit generally used to fall down either on right or left side of the female with a typical groaning sound. Mating of closely related individual was avoided as far as possible to keep the inbreeding at its lowest level. Immediately after 25th day of successful mating, the pregnant doe was shifted to kindling pen, and dry as well as clean jute wool was provided for preparing nest for the new born kits. The lactating doe and kits were kept together in individual nest box up to 42 days of age and then kits were gradually separated (weaning) to individual wire cages of standard dimensions under similar housing and management practices. Sexing and ear tagging were done at the time of weaning. Besides symptomatic treatment, standard prophylactic schedule was adopted in disease management.

Recording of body weights, wool yield and quality: The live body weight (empty stomach) of individual animals at weaning (6th week of age) and at post weaning (8th, 10th, 12th, 14th, 16th, 18th, 20th, 22th and 24th weeks of age) was recorded in grams using digital weighing balance with high precision (i.e. 100 mg) during morning hours for a period of four years (2018 to 2021). Each animal were sheared regularly at an interval of 75 days after first shearing, which was carried out at 56 days of age. Shearing was done manually with shearing scissors. The necessary precautions were taken during shearing to maintain the uniformity in wool yield and quality parameters. While shearing, care was taken to cut the wool as close to the skin in a single cut. The wool yields were recorded in grams for individual rabbit after each shearing using digital weighing balance. Wool samples of II clip were collected from dorsal region of each animal for estimation of staple length and fiber diameter using Ermascope (Erma India, Chandigarh).

Classification of data and statistical analysis: The data were classified according to different non-genetic factors i.e. season of kindling (4 levels: December-February, March-May, June-August, September-November), year of kindling (4 levels), sex (2 levels) and litter size group at birth (3 levels, i.e. up to 5, 6–8 and above 8). The analysis included 607 animals descended from 65 dams and 56 sires. The number of daughter per sire ranged from 01 to 53 with an average number of daughters per sire was six. The data generated on growth and production traits were analyzed by least squares analysis of variance (Harvey 1990) taking sire as random effect, whereas year and season of kindling, sex of rabbit and litter size group at birth were considered as fixed effect in the statistical model:

$$Y_{ijklmn} = \mu + P_i + T_j + R_k + S_I + Km + e_{ijklmn}$$

Where, Y_{ijklmn}, observation on an individual belonging to ith sire and born in kth season of jth year of the Ith sex in mth litter size at birth; μ, the population means; P_i, random effect of ith sire; T_j, fixed effect of jth year of birth; R_k, fixed effect of kth season of birth; S_I, fixed effect of Ith sex of an individual; K_m, fixed effect of mth litter size at birth; e_{ijklmn}, random error associated with mean 0 and variance σ^2. The genetic and phenotypic parameters of growth and wool traits were estimated using half-sib correlation method. Duncan's Multiple Range Test (DMRT) was done to make pair wise comparison among the means.

RESULTS AND DISCUSSION

Performance traits

Growth performance: The least squares means of body weights (g) at various ages estimated on overall, as well as on year and season of kindling of German Angora rabbits maintained at the North Temperate Regional Station, ICAR-Central Sheep and Wool Research Institute, Garsa are presented in Table 1. The present estimates of body weights at 6th, 18th and 24th week of ages were close to those reported in German Angora rabbit (Singh *et al*. 2004). However, a slightly higher body weight at 6th, 12th, 18th and 24th week of ages of German Angora were also reported (Niranjan *et al*. 2010) in comparison to the present findings. Literature recorded an adult body weight as 2.506 ± 0.0432 kg in French Angora and 2.506 ± 0.033 kg in German Angora rabbit (Assad *et al*. 2017). Differences might be due to diverse strains, lines or breed differences and dissimilar environment and management system.

Wool traits: The least squares means of wool yield (g) at I, II, III and IV clip, and wool characteristics assessed by staple length (cm) and fiber diameter (μ) estimated on overall, as well as on year and season of birth of German Angora rabbit are presented in Table 2. The wool yield increased sharply at subsequent clips at shearing interval of 75 days and attained 119.75 ± 3.25 g wool yield at IV

Table 1. Least squares means ± standard errors of various growth traits in German Angora rabbit

Factor		N	Least squares means± standard errors of body weight (in gram)									
			6th	8th	10th	12th	14th	16th	18th	20th	22th	24th
Overall		607	636±17.6	895±20.6	1132±22.8	1376±28.7	1607±32.2	1809±35.2	2000±31.1	2079±31.1	2211±31.0	2317±32.1
Year of birth	2018	170	784^{a}±31.7	1115^{a}±41.5	1350^{a}±48.8	1618^{a}±58.0	1809^{a}±60.8	2012^{a}±64.3	2204^{a}±63.5	2209^{a}±62.4	2386^{a}±66.3	2504^{a}±62.5
	2019	141	639^{b}±28.7	910^{b}±37.1	1147^{b}±43.3	1372^{b}±51.8	1581^{c}±54.6	1847^{b}±58.0	2008^{c}±56.7	2037^{b}±55.7	2175^{c}±58.9	2297^{c}±55.9
	2020	114	508^{d}±29.1	692^{d}±37.8	899^{c}±44.2	1150^{c}±52.8	1399^{d}±55.6	1569^{d}±58.9	1736^{d}±57.7	1871^{c}±56.8	2013^{d}±60.1	2103^{d}±57.0
	2021	182	613^{c}±31.1	863^{cd}±40.6	1130^{b}±47.7	1365^{b}±56.8	1637^{b}±59.6	1808^{c}±63.0	2053^{b}±62.1	2199^{a}±61.1	2269^{b}±64.8	2364^{b}±61.2
Season of birth	Winter	170	683^{a}±20.1	961^{a}±24.3	1263^{a}±27.5	1484^{a}±34. 0	1735^{a}±37.1	1942^{a}±40.1	2136^{a}±36.9	2232^{a}±36.7	2341^{a}±37.4	2429^{a}±37.4
	Spring	230	592.^{b}±20.5	834^{b}±24.9	1097^{c}±28.3	1370^{b}±34.9	1562^{c}±38.0	1733^{c}±41.0	1937^{c}±37.9	2027^{c}±37.6	2206^{c}±38.5	2281^{b}±38.3
	Summer	118	588^{b}±22.0	820^{b}±27.2	1037^{d}±31.2	1307^{c}±38.0	1515^{d}±41.0	1696^{d}±44.1	1847^{d}±41.4	1920^{d}±41.0	2034^{d}±42.4	2139^{c}±41.6
	Autumn	89	682^{a}±23.3	967^{a}±29.2	1129^{b}±33.7	1344^{b}±40.8	1614^{b}±43.8	1865^{b}±46.9	2080^{b}±44.5	2137^{b}±44.0	2264^{b}±45.8	2420^{a}±44.5
Sex	Males	298	637±18.5	902±21.8	1149^{a}±24.3	1400^{a} ±30.4	1640^{a} ±33.8	1831^{a}±36.8	2012±33.0	2087±32.9	2210±33.1	2292^{a}±33.8
	Females	309	636±18.4	889±21.5	1114^{b}±24.0	1352^{b} ±30.1	1573^{b}±33.5	1787^{b}±36.5	1988±32.6	2071±32.6	2211±32.7	2343^{b}±33.5
Litter size	up to 5	182	729^{a}±20.1	997^{a}±24.3	1217^{a}±27.5	1486^{a}±34.0	1701^{a}±37.1	1901^{a}±40.2	2089^{a}±36.9	2146^{a}±36.7	2284^{a}±37.5	2405^{a}±37.4
	6–8	272	638^{b}±19.4	904^{b}±23.2	1122^{b}±26.1	1385^{b}±32.4	1612^{b}±35.6	1814^{b}±38.6	1995^{b}±35.1	2072^{b}±35.0	2210^{b}±35.5	2316^{b}±35.8
	Above 8	153	542^{c}±20.8	786^{c}±25.3	1056^{c}±28.8	1257^{c}±35.4	1506^{c}±38.5	1713^{c}±41.5	1917^{c}±38.5	2019^{c}±38.2	2139^{c}±39.2	2232^{c}±38.9

N, Number of observations.

Table 2. Least squares mean ± standard errors of various wool yields and its quality in German Angora rabbit

Factor		N	Wool yields at different clips (in gram)				Wool characteristics	
			I clip	II clip	III clip	IV clip	Staple length (cm)	Fiber diameter (μ)
Overall		607	16.63±0.68	72.62±2.31	106.18±2.40 (600)	119.75±3.25(499)	6.33±0.03(572)	13.18±0.04(572)
Year of birth	2018	170	20.01^{a}±1.20	82.90±8.49	109.51^{b}±5.06 (166)	109.27^{c}±6.38(164)	6.39^{b}±0.12(170)	13.19±0.21(170)
	2019	141	15.58^{c}±1.08	70.55±7.35	103.46^{c}±4.50 (141)	106.46^{c}±5.65(136)	6.15^{a}±0.11(133)	13.09±0.18(133)
	2020	114	13.86^{d}±1.10	68.08±7.54	96.25^{d}±4.59 (113)	124.59^{b}±5.87(102)	6.40^{b}±0.11(96)	13.19±0.19(96)
	2021	182	17.08^{b}±1.17	68.95±8.27	115.51^{a}±4.95(180)	138.66^{a}±6.91(97)	6.38^{b}±0.12(173)	13.27±0.20(173)
Season of birth	Winter	170	17.24^{b}±0.77	87.73^{a}±3.72	101.60^{bc}±2.89(168)	116.68±3.79(162)	6.33±0.05(165)	13.03±0.08(165)
	Spring	230	15.09^{c}±0.79	59.78^{c}±3.94	100.41^{c}±2.97(229)	118.95±4.13(182)	6.35±0.06(211)	13.31±0.09(211)
	Summer	118	15.11^{c}±0.84	69.31^{b}±4.64	104.35^{b}±3.26(117)	122.83±4.63(70)	6.32±0.07(110)	13.22±0.11(110)
	Autumn	89	19.10^{a}±0.89	73.66^{b}±5.24	118.37^{a}±3.54(86)	120.51±4.49(85)	6.33±0.07(86)	13.18±0.12(86)
Sex	Males	298	16.45±0.71	72.22±2.83	102.28^{a}±2.57(295)	119.23±3.45(238)	6.29^{a}±0.04(285)	13.21±0.06(285)
	Females	309	16.81±0.71	73.02±2.73	110.09^{b}±2.53(305)	120.26±3.40(261)	6.38^{b}±0.04(287)	13.16±0.05(287)
Litter size	up to 5	182	19.60^{a}±0.77	79.07±3.74	106.03^{a}±2.89(180)	121.18±3.88(149)	6.30±0.05(172)	13.22±0.08(172)
	6–8	272	16.89^{b}±0.74	72.64±3.34	107.89^{a}±2.74(270)	122.48±3.77(225)	6.36±0.05(252)	13.14±0.07(252)
	above 8	153	13.41^{c}±0.79	66.15±4.07	104.63^{b}±3.03(150)	115.58±4.07(125)	6.34±0.06(148)	13.20±0.09(148)

N, Number of observations; Figures within parentheses denote number of observations.

clip. The present estimates were in accordance to those reported earlier in German Angora rabbit for I and II clip (Singh *et al.* 2004). However, a slightly higher wool yield (22.01, 90.13, 148.34 g in I, II and III clip, respectively) of German Angora was reported in another study (Niranjan *et al*. 2011). Literature also recorded wool yield of German Angora rabbits at I, II, III and IV clip at 3 month shearing interval as 58.77 ± 35.10, 169.77 ± 30.38, 181.00 ± 21.30 and 184.73 ± 23.49 g, respectively (Sarma *et al.* 2020). Singh *et al*. (2008) recorded the corresponding estimates as 160.45 ± 7.85, 142.25 ± 5.20, 165.35 ± 5.25 and 135.85 ± 6.22 g wool for an adult flock of German Angora rabbits. The attributed difference in wool yield might be due to their different age groups or shearing interval, shedding of wool due to mite infestation or harsh climatic conditions and quality feed and fodder available, etc. It was uniformly observed in all the studies that wool yield at first clip was lowest and increased in subsequent clips. This could be attributed to the reason that less numbers of hair follicles per unit area be present at the time of I clip and they subsequently increase with the maturity of the animals. The wool quality at II clip, i.e. staple length and fiber diameter had the estimated means as 6.33 ± 0.03 cm and 13.18 ± 0.04 μ, respectively, which were in close agreement with other reports in German Angora rabbits (Ramakrishna *et al*. 2004, Singh *et al*. 2006). However, a slightly lower estimate was reported in Angora rabbits by Assad *et al.* 2017 and Khan *et al.* 2020.

Effect of genetic and non-genetic factors on various quantitative traits

Effect of sire: The least squares analysis of variance revealed highly significant effect of sire ($P \leq 0.01$) on the estimates of body weights at all ages and wool yield at all clips. However, a non-significant effect of sire was observed on the wool quality traits (staple length and fiber diameter).

Effect of year of kindling: The analysis also revealed a significant ($P<0.01$) effect of year of kindling/ birth on all growth performance traits. The highest body weights were observed during 2018, whereas the lowest body weights were found during 2020 (Table 1). Our results were in concordance with the reports in White Giant and Soviet Chinchilla rabbits (Sivakumar *et al*. 2012 and Apori *et al*. 2014). The effect of year of kindling was highly significant ($P <0.01$) on wool yield at I, III and IV clip and staple length, whereas non-significant on II clip wool yield and fiber diameter (Table 2). Similar to the present findings, the significant effect of year of kindling on wool yield was reported in German Angora rabbit (Sarma *et al*. 2020) and in French Angora rabbits (Thebault *et al.* 1992). The animals born during 2018 were found to have the highest performance and they differed significantly ($P<0.01$) with the values observed in other years. The influence of year of kindling might be due to variation in management practices, change in environmental condition and feeding practices over the years.

Effect of season of kindling: Season of kindling had a highly significant ($P<0.01$) influence on the body weights at all ages (Table 1) and wool yield at I, II and III clips (Table 2). Kits born during the winter season had higher body weights from weaning upto 24th weeks of age followed by autumn season, which might be due to ample availability of good quality fodder during these seasons. The kits born in summer recorded the lowest body weights, which might be due to rise in environmental temperature along with humidity leading to stress to both doe as well as kits and decreased feed intake with increasing temperature. The decreased body weight in summer was in agreement with the findings of Belhadi *et al*. (2002) in local rabbit raised in Algeria and Rojan *et al*. (2017) in broiler breeds of rabbit. Ghosh *et al.* (2008) and Dige *et al.* (2012) also reported significant seasonal variation in body weights in New Zealand White rabbit. The wool yield at I, II and III clip differed significantly among different seasons with the highest yield during winter season followed by autumn season. Similar significant seasonal effects on wool yield at different clips were reported by Sood *et al.* (2007), Bhatt and Sharma (2009) and Sarma *et al* (2020) in German Angora rabbits. The growth before weaning would be more dependent on maternal effects and thus effect of season could be more important after weaning. The difference associated with season of kindling might be due to impact of heat stress in summer affecting feed intake as well as lack of quality fodder in summer. This might be due to the fact that rabbits born during winter season get more favourable time in most of their growth period.

Influences of sex: Sex had significant effect on body weight from 10th to 16th and 24th week of age. Males were significantly ($P<0.05$) heavier than females at 10th to 16th week of age. However, female were significantly heavier than males at 24th week of age week (Table 1). A non-significant effect of sex on all the post weaning body weights was reported by Poornima *et al*. (2002) in Californian white rabbits. Female angora rabbits yielded higher wool than males. However, the significant effect of sex was recorded on III clip wool yield and staple length, which were in accordance with the finding of Risam *et al*. (2004) in German Angora rabbit. Significant effect of sex on wool yield was also reported by Sood *et al.* (2007). However, non-significant effect of sex on wool yield was reported by Assad *et al*. (2017) and Sarma *et al*. (2020) in Angora rabbits.

Influence of litter size at birth: The litter size at birth significantly ($P<0.01$) affected the body weights at all ages (Table 1) and wool yield at I and III clips (Table 2). These results were in agreement with the findings of Kumar *et al.* (2001) in three broiler breeds of rabbit, viz. White Giant, Soviet Chinchilla and Black Brown and Gupta *et al*. (2002) in broiler rabbits and their crosses. The body weight and wool yield gradually declined as the litter size at birth increased. A similar trend was also reported by Rojan *et al*. (2017) in White Giant, Soviet Chinchilla and Grey Giant breeds of rabbit and Belhadi *et al*. (2002) in local rabbits of

Table 3. Estimates of heritability (at diagonal), phenotypic (above diagonal) and genetic (below diagonal) correlations among growth traits in German Angora rabbit

Trait	6th	8th	10th	12th	14th	16th	18th	20th	22th	24th
6th	0. 89±0.19	0.85	0.74	0.67	0.67	0.61	0.85	0.57	0.53	0.46
8th	0.91±0.04	0.77±0.17	0.83	0.76	0.74	0.70	1.00	0.64	0.60	0.51
10th	0.70±0.10	0.86±0.06	0.67±0.16	0.78	0.72	0.68	0.83	0.65	0.59	0.51
12th	0.71±0.10	0.88±0.05	0.86±0.06	0.77±0.17	0.78	0.68	0.76	0.65	0.61	0.55
14th	0.73±0.09	0.82±0.07	0.76±0.09	0.88±0.05	0.91±0.18	0.82	0.74	0.70	0.66	0.61
16th	0.69±0.10	0.85±0.06	0.80±0.08	0.85±0.06	0.94±0.03	0.94±0.19	0.70	0.73	0.66	0.65
18th	0.91±0.04	0.99±0.00	0.86±0.06	0.88±0.05	0.82±0.07	0.85±0.06	0.77±0.17	0.64	0.60	0.51
20th	0.61±0.12	0.83±0.08	0.72±0.10	0.78±0.08	0.85±0.06	0.92±0.04	0.83±0.08	0.79±0.17	0.77	0.67
22th	0.54±0.14	0.69±0.11	0.58±0.14	0.71±0.11	0.77±0.09	0.85±0.07	0.69±0.11	0.90±0.05	0.67±0.16	0.71
24th	0.51±0.14	0.57±0.13	0.52±0.15	0.66±0.11	0.76±0.09	0.78±0.08	0.57±0.13	0.83±0.07	0.73±0.10	0.84±0.18

Table 4. Estimates of heritability (at diagonal), phenotypic (above diagonal) and genetic (below diagonal) correlations among wool traits in German Angora rabbit

Trait	Wool yield (g)				Wool characteristics	
	I clip	II clip	III clip	IV clip	Staple length	Fiber diameter
I clip	0.58±0.22	0.23	0.23	0.24	0.05	0.07
II clip	0.29±0.28	0.20±0.13	0.31	0.17	0.01	-0.01
III clip	0.39±0.18	0.82±0.26	0.65±0.18	0.56	0.03	0.07
IV clip	0.20±0.20	0.14±0.34	0.78±0.12	0.66±0.18	-0.02	0.08
Staple length	0.23±0.34	0.77±0.61	-0.04±0.39	-0.35±0.40	0.14±0.12	-0.06
Fiber diameter	NA	NA	NA	NA	NA	NA

NA= Not estimated

Algeria. The competition among the individual foetuses in the uterus and limited capacity of a doe to provide nutrients and space to large number of kits in her womb during the pregnancy in addition to insufficient milk during lactation period could be the cause of lower performance of kits born in larger litters (Gupta *et al*. 2002).

Genetic parameters: The estimates of heritability, genetic and phenotypic correlations of body weights and various wool traits are presented in Table 3 and 4, respectively**.** The heritability estimates for all growth traits were high in magnitude and were associated with low standard errors suggestive of reliable and precise estimates. The present high heritability estimates for growth traits were comparable to those reported in different breeds of rabbits (Singh and Jilani 2006, Sivakumar *et al.* 2012, Sakthivel *et al*. 2017, Abe *et al*. 2018). The high h^2 estimates for weaning weight in the present study were in agreement with the earlier estimates (0.94) reported by Khan *et al*. (2018) for local rabbits by paternal half sib method. The high estimate of heritability of weaning weight was also reported in German Angora rabbits by Singh *et al.* (2008). Similarly, Rojan *et al*. (2009) also reported high heritability for 10th (0.80), 12th (0.65) and 14th (0.71) weeks body weight using half sib correlation method. The higher estimates of heritability could be indicative of an individual genotype governance for different traits and hence individual selection would be recommended for further genetic improvement of these traits. Discrepancies between the estimates, heritability values depend on the genetic makeup of the stocks, management and climatic conditions and period of study as well as differences in data size, models of data correction and method of analysis. All the estimates for genetic and phenotypic correlation coefficients of growth trait were found to be positive and ranged from high (0.51 ± 0.14) to extreme high (0.99 ± 0.14) in magnitude among all the intra biweekly body weights (Table 3). The weaning weight had high and positive genetic as well as phenotypic correlations with different post weaning weights indicating the usefulness of early body weight as selection criterion for genetic improvement of body weights at later ages.

The heritability estimates of wool yield at I clip, II clip, III clip, IV clip and staple length were in close agreement with the estimates for wool yield at different clips reported in German Angora rabbit (Singh *et al.* 2008) and in French Angora rabbit (Rafat *et al*. 2009). The differences in the heritability estimates might be due to the variation in the data size, genetic variation within population, management and environmental conditions as well as the methods used for the estimation (Ayalew *et al.* 2017). The highly heritable traits in the present study indicated that genetic variation was existing in the population and there is scope for improvement through genetic selection rather than these traits being improved though suitable management practices. The genetic and phenotypic correlations among wool yield at different clips were positive and low to moderate in magnitude, which were in close agreement with the estimates reported in German Angora rabbit (Niranjan *et al*. 2011). Similarly, a very low genetic and phenotypic correlation among wool clips in French Angora rabbits was also reported by Rafat *et al*. (2009). The genetic correlations of wool yield with staple length were positive for I and II clips and negative for III and IV clips. There were reports that the growth traits were highly and positively correlated with wool yield in German Angora (Garcia and Magofk 1982 and Singh *et al*. 2006). The correlations of wool quality traits with clip yield were very low in magnitude and were observed to be inconsistent in the present study.

The genetic improvement of German Angora rabbit in any organized farm depends on genetic evaluation of their growth and production traits over the years. The present investigation demonstrated the importance of highly significant sire effect and some non-genetic factors on growth and wool traits in German Angora rabbit, which could be utilized for genetic improvement of the rabbits. Winter might be considered as the best season for kindling of Angora rabbits for optimum growth and wool production performances under sub-temperate climatic condition. Individual selection would be recommended for further genetic improvement. The pure German Angora rabbit can be exploited for backyard rabbit production and thus could play a significant role in livelihood and nutritional security.

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REFERENCES

Abe O S, Amusan S A and Ozoje M O. 2018. Genetic analysis of growth pattern in New Zealand White rabbit fed commercial grower mash. *Nigerian Journal of Animal Science* **20**(4): 347–54.

Apori S O, Hagan J K and Osei D. 2014. The growth and reproductive performance of different breeds of rabbits kept under warm and humid environments in Ghana. *Online Journal of Animal and Feed Research* **4**(3): 51–59.

Assad N I, Khan N N, Alam S and Chakraborty D. 2017. Performance of wool type angora rabbits under temperate conditions of Kashmir (J&K), India. *Journal of Applied and Natural Science* **9**(2): 1022–25.

Ayalew W, Aliy M and Negussie E. 2017. Estimation of genetic parameters of the productive and reproductive traits in Ethiopian Holstein using multi-trait models. *Asian-Australasian Journal of Animal Science* **30**(11): 1550–56.

Belhadi S, Boukir M and Amriou L. 2002. Non-genetic factors effecting rabbit reproduction in Algeria. *World Rabbit Science* **10**: 103–09.

Bhatt R S and Sharma S R. 2009. Seasonal production performance of Angora rabbits under sub-temperate Himalayan conditions. *Asian-Australasian Journal of Animal Science* **22**(3): 416–20.

Dige M S, Kumar A, Kumar P, Dubey P P and Bhushan B. 2012. Estimation of variance components and genetic parameters for growth traits in New Zealand White rabbit (*Oryctolagus cuniculus*). *Journal of Applied Animal Research* **40**(6): 16–172.

Falconer D S and Mackay T F C. 1996. *Introduction to Quantitative Genetics*. Longmans Green, Harlow, Essex, UK.

Garcia F X and Magofke J C. 1982. Genetic parameters for the production of fleece and body weight in Angora rabbits. *Advanced Production Animal* **12**: 81–90.

Ghosh S K, Das A, Bujarbaruah K M, Das A, Dhiman, K R and Singh N P. 2008. Effect of breed and season on rabbit production under subtropical climate. *World Rabbit Science* **16**: 29–33.

Gupta B R Rao V P Reddy C E, Satyanarayana A and Reddy P P. 2002. Effect of genetic and non-genetic factors on post-weaning body weights and carcass traits of broiler rabbits. *Indian Journal of Animal Sciences* **72**(1): 70–74.

Harvey W R 1990. User's guide for LSMLMW, mixed model least squares and maximum likelihood computer programme. Ohio State University (Mimeograph).

Khan K, Suhail S M, Ahmad I, Ahmad I, Ijaz A, Abdullah A, Hussain S, Khan S and Ahmad N. 2018. Growth traits and genetic potential of local rabbits. *International Journal of Biosciences* **13**(4): 444–49.

Khan N N, Hamadani A, Dar E, Shabir M, Bukhari S, Shah R, Ayaz A and Rather M A. 2020. Breed effect and effect of non-genetic factors on performance traits of wool type Angora rabbits in an organized farm of Kashmir. *International Journal of Current Microbiology and Applied Sci*ences **9**(6): 676–81.

Kumar S, Gulyani R, Kumar V and Singh R N. 2001. Effect of genetic and non-genetic factors on weekly body weight of broiler rabbits in semi arid-region of Rajasthan. *Indian Journal of Animal Sciences* **71**(11): 1075–77

Niranjan S K, Sharma S R and Gowane G R. 2010. Estimates of direct and maternal effects on growth traits in Angora rabbits. *Asian-Australasian Journal of Animal Sciences* **23**(8): 981–86.

Niranjan S K, Sharma S R and Gowane G R. 2011. Estimation of genetic parameters for wool traits in Angora rabbit. *Asian-Australasian Journal of Animal Science* **24**(10): 1335–40.

Ossard H, Thebault, Vrillon R G, Allain J L D and De-Rochambeau H. 1995. *Economic Overview of the French and World Markets for Angora Rabbit Wool*. European fine fiber network, occasional publication No: **5**: 35–47.

Pokharna A K, Gupta N P, Patni P C, Arora R K and Shakyawar D B. 2004. Processing of Angora rabbit wool. National seminar on Angora rabbit wool and Cashmere production and utilization. Pp. 166–73. 25–26th September 2004. Manali (HP).

Poornima K, Gupta R B, Rao G N and Satyanarayana A. 2002. Factors affecting genetic study on post-weaning body weights and growth rates of Californian white rabbits. *Indian Journal of Animal Research* **36**(1): 39–42.

Rafat S A, Thebault R G, Bonnet M, Deretz S, Pena-Arnaud B, Rochambeau H-de and Allain D. 2009. A note on divergent selection for total fleece weight in adult Angora rabbits: Direct response to selection on total fleece weight at first and second harvest. *World Rabbit Science* **17**: 39–44.

Ramakrishna C, Chaturvedi V B, Kumar A, Bhanuprakash V, Sharma A K and Rasool T J. 2004. Performance of Angora Rabbits in Mukteswar. *National Seminar on Angora rabbit wool and Cashmir production and utilization*, 25-26th September, Manali, H.P., India, Souvenir of lead papers and abstracts, pp.222 (Abstract 51).

Risam K S, Singh U and Kumar D. 2004. Wool production of improved German Angora rabbit under sub temperate condition in Himachal Pradesh. *National Seminar on Angora rabbit wool and Cashmir production and utilization*, 25-26th

September, Manali, H.P., India, Souvenir of lead papers and abstracts, pp.195.

Rojan P M, Bindu K A and Raja T V. 2017. Effect of genetic and non-genetic factors on post-weaning body weight in rabbits. *Global Journal of Animal Breeding and Genetics* **1**: 16–19.

Sakthivel M, Balasubramanyam D, Kumarasamy P, Gopi H, Raja A, Anilkumar R and Devaki A. 2017. Estimates of (co) variance components and genetic parameters for body weights and growth efficiency traits in the New Zealand white rabbit. *World Rabbit Science* **25**: 329–38.

Sarma L, Katoch S, Thakur Y P and Sankhyan V. 2020. Estimation of genetic parameters and influence of non-genetic factors on wool yields in German Angora rabbits. *International journal of Current Microbiology and Applied Sciences* **9**(8): 3799–07.

Singh C B and Jilani M H. 2006. Genetic studies on the reproductive and productive traits of German Angora rabbits under temperate condition of Garhwal Himalayas. *Indian Journal of Small Ruminant* **12**(1): 26–32.

Singh C B, Singh V and Jilani M H. 2008. Genetics studies on reproductive and productive traits German Angora rabbits under temperate climatic conditions of Garhwal Himalayas. *Indian Journal of Animal Sciences* **78**(3): 285–88.

Singh U, Sharma S R, Bhatt R S, Kumar D and Risam K S. 2006. Effect of shearing intervals on the growth and wool parameters of German Angora rabbits. *Indian Journal of Animal Sciences* **76**: 88–91.

Singh U, Sharmn S R, Bhati R S, Risam K S, Kumar D. Sawav R K and Swaiw N. 2004. Effect of parity on the production performance of German Angora rabbits *Indian Journal of Animal Sciences* **74**(5): 547–49.

Sivakumar K, Kumar V R S, Thiruvenkadan A K, Saravanan R and Jeyakumar M. 2012. Production and reproduction performances of exotic breeds of rabbit under tropical climatic conditions of Tamil Nadu. *Indian Journal of Animal Sciences* **82**(4): 415–18.

Sood A, Gupta K, Risam K S, Katoch S and Kaila O P. 2007. Non-genetic factors affecting wool yield in angora rabbits. *Indian Journal of Animal Research* **41**(3): 233–34.

Thebault R G Vrillon J L, Allain D, Fahrat E and Rochambeau H-de. 1992. Effect of non-genetic factors on quantitative and qualitative features of Angora wool production at French farms. *Journal of Applied Rabbit Research* **15**: 1568–75.