
Volume 94, Issues 1–3, November 2010 ISSN 0921-4488
ELSEVIER
SMALL RUMINANT RESEARCH
The Official Journal of the International Goat Association

Small Ruminant Research 94 (2010) 10–16

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Crossbreeding components for growth, carcass and meat composition traits in crossing Saudi Aradi with Damascus goats

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ARTICLE INFO

Article history:
Received 12 April 2009
Received in revised form 8 May 2010
Accepted 19 May 2010
Available online 9 September 2010

Keywords:
Goats
Crossbreeding
Growth
Carcass
Meat quality
Direct additive
Direct heterosis
Maternal heterosis

ABSTRACT

A three-year crossbreeding program between Aradi Saudi breed (A) with Syrian Damascus breed (D) was carried out in two experiments (one in Jouf and the second in Qassim, Saudi Arabia) to produce four genetic groups of AA, DD, 1/2D1/2A and 3/4D1/4A in each experiment separately. A total number of 677 kids fathered by 36 sires and mothered by 335 dams were used to evaluate performance of kids in terms of growth, carcass and meat composition traits. A generalized least squares procedure was used to estimate direct additive genetic effects and direct and maternal heterosis. All estimates of direct additive effects for growth traits in Jouf experiment were significantly high and in favour of Damascus kids by 12.0–31.9% for body weights and 13.7–30.6% for daily weight gains compared to the founder breeds ($p < 0.01$), while in Qassim experiment the estimates ranged from 17.1 to 34.2% for body weights and from 12.3 to 37.2% for daily weight gains ($p < 0.01$). Estimates of direct genetic effects for carcass traits were mostly significantly in favour of Damascus goats, but these estimates were in favour of Aradi goats for meat compositions. Moderate and significant direct genetic effects for some carcass traits were in favour of Damascus goats by percentages ranging from 11.7 to 48.6% ($p < 0.05$ or $p < 0.01$) relative to the average of founder breeds. Lean of Aradi kids had higher direct additive effects by 15.7% for dry matter content ($p < 0.01$) and by 2.8% for ether extract than lean of Damascus kids. Crossbred kids were associated with significant direct heterosis in the majority of growth traits since heterotic increments were 0.16, 0.76, 0.93, 1.20, 0.79, 0.55 and 1.39 kg in Jouf experiment ($p < 0.05$) at 0, 4, 8, 12, 16, 20 and 24 weeks of age, while the respective increments in Qassim experiment were 0.31, 0.52, 1.39, 1.49, 1.43, 1.80 and 1.56 kg ($p < 0.05$ or $p < 0.01$). Pre-slaughter weight, hot carcass weight, and weights of head, skin, heart, and kidneys showed favourable positive estimates of direct heterosis of 1.35, 0.8 kg, 125, 93, 62, and 16 g, respectively. Estimates of maternal heterosis for growth traits in Jouf experiment are mostly positively significant since these estimates were ranging from 2.4 to 10.7% for body weights and 2.4–8.4% for daily weight gains, i.e. crossbred dams of kids had moderate heterotic maternity over their purebred dams in most growth traits studied.

1. Introduction

In order to improve productivity of goats in Saudi Arabia, there is a great deal of interest to increase productivity of native goat breeds through crossbreeding and upgrading programs. These programs together with selection are required to characterize genetically these local goat

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0921-4488/$ – see front matter © 2010 Published by Elsevier B.V.
doi:10.1016/j.smallrumres.2010.05.020

breeds as well as of the so-called exotic breeds that could be used for genetic improvement (Barillet, 2007; Fahmy and Shrestha, 2000; Shrestha and Fahmy, 2007a,b). Since 2006, a goat research project was initiated in Saudi Arabia between Qassim University and Camel Research Centre of Ministry of Agriculture to develop new lines of meat and milk goats adapted to hot climate (Al-Saef, 2009). This program is based on crossing bucks of meat-type sire breeds with does of fecund-type dam breed to produce kids with improved growth rate and carcass quality. Accordingly, Damascus breed was then crossed with a local breed named Saudi Aradi since Aradi goat is characterized by twinges as a local breed in Saudi Arabia (Salah et al., 1989; Dosari et al., 1996), while Damascus goats are normally considered as a dual purpose breed (meat and milk) adaptable to harsh climate (Mavrogenis et al., 1984a,b). However, the Aradi goats are prevalent to be reared in Saudi Arabia at the eastern parts of the Gulf region. Live weight 34.4 ± 3.9 kg; faster body gain or growth rate of 149 g/day and milk yield of 160.3 ± 6.37 kg/lactation (Dosari et al., 1996). Al-Dobaib et al. (2009) reported that the daily milk yield averaged 1094 g and this result for milk yield was moderate under hot climate. Sawaya et al. (1984) in Saudi Arabia reported that milk production of Aradi goats was relatively low (60–150 kg/year) and they concluded that these goats can produce milk steadily even during periods of drought and, therefore, they are greatly appreciated by desert dwellers. Aradi goats could record higher production than the other local breeds under the same conditions and therefore more attention should be paid to this breed. Unfortunately, reviewed studies concerning crossbreeding analysis for growth, carcass and meat quality traits in goats raised in hot climate countries are scarce. The main objective of the present study was mainly to genetically evaluate growth, carcass and meat quality traits in a crossbreeding program involving a Saudi Aradi breed (A) and a Damascus breed (D) in terms of additive and heterotic effects.

2. Materials and methods

2.1. Crossbreeding plan and management

A three-year crossbreeding program between Saudi Aradi goats (A) and Syrian Damascus goats (D) was started since 2006 in Camel Research Centre in Jouf and Animal Production Research Station in Qassim University, Saudi Arabia. Does were locally born in both farms and they were in the first kidding. The objective of the crossing program was to indicate which way to go synthetic breed or continuous crossing. Does of Aradi goats were randomly divided into two groups (120 doe in each group) representing two experiments one in Jouf and the second in Qassim. In each experiment, Aradi does were subdivided into two subgroups; one division was inseminated artificially from semen of bucks of the same breed and the second division was inseminated artificially from semen of bucks of Damascus breed, producing a genetic group of 1/2D1/2A. Crossbred does of 1/2D1/2A were backcrossed to Damascus bucks to get the genetic group of 3/4D1/4A. In both experiments, does of Damascus breed were inseminated from bucks of the same breed to produce purebred litters and kids. In such crossbreeding program, four genetic groups of AA, DD, 1/2D1/2A and 3/4D1/4A were produced in each experiment and this program of crossbreeding is still running and granted for three years more up to year of 2011. Bucks were evaluated for semen characteristics and does were estrus synchronized using intravaginal progestagen sponges containing 30–40 fluorogestone acetate (FGA) or controlled internal drug release (CIDR) device containing 60 mg progesterone. Pregnancy was diagnosed 45–60 days post-insemination with the aid of ultrasound scanner. Till now, a total number of 677 kids fathered by 36 sires and mothered by 335 dams were obtained as shown in Table 1. Kids were weaned at three months of age. It is important to indicate numbers in the year-season subclasses, and the definition of season to validate conclusions drawn from them. Since a limited number of 3/4 D 1/4 A kids were available now in Qassim experiment and therefore data of this group were excluded from statistical and genetic analyses. Details of housing and feeding were described by Al-Saef (2009).

Table 1
Number of does and bucks used in mating and number of kids born.

Item	Jouf experiment	Qassim experiment	Total
Does			
Aradi	98	143	241
Damascus	10	7	17
1/2D1/2A	73	4	77
Bucks			
Aradi	10	9	19
Damascus	14	3	17
Kids born			
Aradi	169	97	266
Damascus	28	19	47
1/2D1/2A	140	134	274
3/4D1/4A	90	–	90
Total	427	250	677

2.2. Slaughtering experiment

At 6 months of age, male kids representing each genetic group in Qassim experiment only were randomly slaughtered and dissected for edible parts and non-edible ones. Hot carcasses were weighed and dressing percentages were calculated. The weights of head, fur, viscera and offal (representing heart, liver, lungs, kidneys, spleen) were also recorded. A sample of the lean was taken from each animal and chemically analysed according to AOAC (1990) for dry matter (using an air-evacuated oven for 16 h), crude protein (N ×6.25), ether extract and ash.

2.3. Data collected

Live body weights were recorded at birth (0 week) and biweekly thereafter up to 24 weeks of age, while daily gains in weight were computed at four-week intervals. Carcass traits (included hot carcass weight, dressing percent, and weights of head, fur, offal, and viscera) and meat compositions (included percentages of dry matter, crude protein, ether extract, and ash) were investigated.

2.4. Statistical analysis and estimation of crossbreeding effects

Data of each experiment were analysed separately. The following single-trait animal model in matrix notation (Boldman et al., 1995) was used to analyse growth traits within station:

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{b} + \boldsymbol{Z_a}\boldsymbol{u_a} + \boldsymbol{Z_c}\boldsymbol{u_c} + \boldsymbol{e}$$

where $\mathbf{y}$ is the vector of observed trait for kids; $\mathbf{b}$ is the vector of fixed effects of genetic group, sex, year-season of birth (1 = hot months and 2 = moderate months), litter size; $\mathbf{u_a}$ is the vector of random effect of the kid; $\mathbf{u_c}$ is the vector of random non-additive common litter effects; $\mathbf{X}$, $\mathbf{Z_a}$ and $\mathbf{Z_c}$ are the incidence matrices relating records to the fixed effects, additive genetic effects, and common litter effects, respectively; and $\mathbf{e}$ is the vector of random error. Because only the males were slaughtered and the preliminary statistical analysis showed non-significant for litter size, data of carcass traits and meat compositions were analysed using the same animal model after excluding the effects of sex and litter size from the model.

Variance components of Var($\mathbf{u_a}$) = $\mathbf{A}\sigma^2{}_a$, since $\mathbf{A}$ is the numerator relationship matrix, Var($\mathbf{u_c}$) = $\mathbf{I}\sigma^2{}_c$ and Var($\mathbf{e}$) = $\mathbf{I}\sigma^2{}_e$ were estimated using DFREML software of Boldman et al. (1995); where $\sigma^2{}_A$, $\sigma^2{}_c$ and $\sigma^2{}_e$ are variances due to the random effects of direct additive effect, common litter environment, and random error, respectively. Heritability estimates and common litter effects for different traits used in this study were given

Table 2
Genetic groups of kids with their sires and dams and coefficients of the matrix relating genetic group means of kids with crossbreeding parameters.

Genetic group				Mean	Coefficients of the matrix			
Kid	Sire	Dam	Grand-dam		D_A	D_D	H^I	H^M
AA	A	A		1	1	0	0	0
DD	D	D		1	0	1	0	0
1/2D1/2A	D	A		1	0.5	0.5	1	0
3/4D1/4A	D	1/2D1/2A	A	1	0.25	0.75	0.5	1

D_A and D_D, direct additive genetic effects for the Aradi breed and the Damascus breed, respectively; H^I, direct heterosis; H^M, maternal heterosis.

in Al-Saef (2009). These estimates were used to solve the corresponding mixed model equations, obtaining solutions for the genetic group means and their error variance–covariance matrix, using the PEST program (Groeneveld, 2006). The procedure of generalized least squares (GLS) using CBE program of Wolf (1996) was used to estimate crossbreeding effects. The following model of Dickerson as summarized by Dickerson (1992) and Wolf et al. (1995) was used:

$$\boldsymbol{y} = \boldsymbol{Xb} + \boldsymbol{e}, \quad \mathrm{Var}(\boldsymbol{y}) = \boldsymbol{V}$$

where **y** is the vector of genetic groups means, **X** is the incidence matrix of the coefficients for crossbreeding effects, **b** is the vector of crossbreeding genetic parameters, **e** is the vector of residual effects, and **V** is the full covariance matrix of **y**. The coefficients relating genetic crossbreeding parameters to the means of the genetic groups are shown in Table 2 (Wolf et al., 1995). Because the reciprocal cross of Aradi × Damascus was not carried out, the maternal additive effects showed a high co-linearity with the direct additive effects because the corresponding errors highly correlated. For this reason, the maternal additive effects have been excluded from the model. The crossbreeding parameters of direct additive effects and direct and maternal heterosis were estimated using the CBE program of Wolf (1996). The parameters representing differences between the breeds in terms of direct additive genetic effects ($G^I = G^I_A - G^I_D$), direct heterosis (H^I) and maternal heterosis (H^M) were estimated. Thus, we have three parameters to be estimated (a vector called **b**-vector):

$$\boldsymbol{b} = \left[(G^I_A - G^I_D) \quad H^I \quad H^M \right]$$

The estimates of **b** were calculated by the method of generalized least squares (GLS) using the following equation:

$$\hat{\boldsymbol{b}} = (\boldsymbol{X}'\boldsymbol{V}^-\boldsymbol{X})^{-1}\boldsymbol{X}'\boldsymbol{V}^-\boldsymbol{y}$$

where **X** was the matrix of coefficients of estimable crossbreeding effects, coming from Table 2, with the variance–covariance matrix of the estimate of *b* being,

$$\mathrm{Var}(\hat{\boldsymbol{b}}) = (\boldsymbol{X}'\boldsymbol{V}^-\boldsymbol{X})^{-1}$$

This matrix was used to test the significance of the crossbreeding effects.

3. Results and discussion

3.1. Direct additive genetic effects

The estimates for daily gain in weight were in favour of Damascus goats by values ranging from 21 to 47 g in Jouf experiment and 16–54 g in Qassim experiment ($p < 0.01$). However, all estimates of direct additive effects for growth traits in both experiments were significantly high ($p < 0.01$) and in favour of Damascus goats by values ranging from 12.0 to 31.9% in Jouf experiment and from 12.3 to 37.2% in Qassim experiment relative to the founder breeds (Table 3). Mugambi et al. (2007) through crossing of Toggenburg (T), Anglo-Nubian (N), Small East African (E) and Galla (G) breeds in Kenya found that Anglo-Nubian had the highest direct additive effects for weaning weight (+1.69 kg), yearling weight (+1.74 kg) and pre-weaning daily gain (+13.28 g) relative to Small East African breed, while Galla breed recorded higher direct genetic effects than the small East African goat in all traits except the yearling weight, reflecting the ability of this breed to survive in harsh environmental conditions and poor quality feeds. For kids obtained from crossing Alpines with Nubian breed, Gebrelul et al. (1994) in USA reported small and neg-

Table 3
Estimates of direct additive effects and their standard errors ($D^I \pm SE$) for growth traits in Jouf and Qassim experiments.

Trait	Jouf experiment $D^I = (D^I_A - D^I_D)$			Qassim experiment $D^I = (D^I_A - D^I_D)$		
	Estimate	SE	D^I%[a]	Estimate	SE	D^I%[a]
Body weight (kg)						
0 week	−0.39**	0.06	−12.0	−0.87**	0.16	−24.7
4 weeks	−2.53**	0.08	−29.1	−2.72**	0.48	−34.0
8 weeks	−3.82**	0.12	−29.1	−3.25**	0.82	−26.2
12 weeks	−4.99**	0.13	−31.9	−2.65**	1.09	−17.1
16 weeks	−5.59**	0.15	−29.6	−3.77**	1.51	−20.5
20 weeks	−6.23**	0.15	−27.5	−4.76**	1.54	−22.9
24 weeks	−4.20**	0.19	−16.7	−4.87**	1.64	−20.9
Daily gain in weight (g)						
0–4 weeks	−47.0**	7.1	−27.2	−52.1**	4.1	−33.8
4–8 weeks	−21.1**	6.2	−13.9	−36.2**	8.2	−24.0
8–12 weeks	−39.1**	6.3	−30.6	−54.0**	5.2	−37.2
12–16 weeks	−24.1**	6.1	−16.5	−26.1**	4.1	−21.1
16–20 weeks	−47.0**	4.2	−25.1	−34.2**	2.2	−25.9
20–24 weeks	−40.1**	3.1	−22.9	−16.3**	4.1	−12.3

[a] D^I% = [D^I in units/(average of purebreds)] × 100.
** $P < 0.01$.

Table 4
Estimates of direct additive effects and their standard errors ($D^I \pm SE$) for carcass and meat composition traits in Qassim experiment.

Trait	$D^I = (D^I{}_A - D^I{}_D)$		
	Estimate	SE	$D^I\%$[a]
Carcass traits			
Pre-slaughter weight (kg)	−6.3**	0.6	−22.4
Hot carcass weight (kg)	−7.1***	1.2	−48.6
Dressing percentage	−5.5*	1.4	−11.7
Head weight (kg)	−0.48**	0.05	−23.7
Fur weight (kg)	−0.08NS	0.22	−4.1
Viscera weight (kg)	−0.01NS	0.02	−1.3
Heart weight (g)	−27**	11.0	−21.0
Liver weight (g)	−128***	18.0	−25
Lungs weight (g)	−52**	8.0	−15.3
Kidneys weight (g)	14*	4.0	14.5
Spleen weight (g)	−17***	2.0	−30.0
Meat chemical composition			
Moisture (%)	0.2NS	0.12	0.2
Dry matter (%)	4.2**	0.43	15.7
Crude protein (%)[b]	0.4NS	0.56	0.5
Ether extract (%)[b]	0.5NS	0.38	2.8
Ash content (%)[b]	0.1NS	0.23	2.2

NS, non-significant.
[a] $D^I\% = D^I$ in units/(average of purebreds)] × 100.
[b] Traits expressed on dry matter basis.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

ative estimates of direct additive effects to be 0.24, 1.9 and 19.8 kg for birth weight, weaning weight and daily weight gain, respectively. In crossing of German Fawn breed and Katjang goats in Malaysia, Hirooka et al. (1997) reported significant direct and maternal additive genetic effects for body weights at birth, 6 and 9 months of age, suggesting large difference in growth rate.

In most cases, the estimates of direct genetic effects for carcass traits were in favour of Damascus goats, but these estimates were in favour of Aradi kids for meat composition traits (Table 4) relative to the average of founder breeds. The percentages of these direct genetic effects were mostly moderate or high and in favour of Damascus kids by values ranging from −48.6 to 14.5%. The positive and significant estimate of direct additive effect for kidney weight (+14 g) was favourable in hot climate area in terms of water metabolism. Dry and hot climate can lead to very rapid water loss and in order for the kidneys to reabsorb water and solutes in a hot condition, the kidneys have to involve very active nephrons, which act as filtration units. Increasing kidney size (Table 4) resulted in an increase in glomerular filtration rate (GFR) and renal plasma flow (RPF) as stated earlier by Mogensen and Andersen (1973). In rats, the renal water re-absorption increased by the increase in quantity and activity of nephrons within kidneys (Schafer, 2004) and for this reason the Aradi goats are well adapted to high-arid climates. In practice, increasing kidney weight as found in this breed could explain the physiological mechanism(s) that governs the water re-absorption of such an animal under desert conditions. On the other hand, the estimates for meat compositions were somewhat low and in favour of Saudi Aradi goats (Table 4). The lean of Aradi kids had slightly more direct additive effects by 15.7% in dry matter ($p < 0.01$) and by 2.8% in ether extract than the lean of Damascus kids. In Australia, Dhanda et al. (1999) concluded that although breed crosses demonstrated an advantage in carcass characteristics, there was no important influence on meat quality and chemical composition.

3.2. Direct heterosis

Estimates of direct heterosis for the majority of growth traits in both experiments were significant (Table 5). For most body weights, the estimates were positive and ranging from 2.4 to 8.7% in Jouf experiment ($p < 0.05$) and 6.5–11.2% in Qassim experiment ($p < 0.05$ or $p < 0.01$) compared with the average of founder breeds. Also, the estimates for most daily weight gains were significantly positive and ranging from 2.9 to 6.7% in Jouf experiment ($p < 0.05$) and 9.1–14.5% in Qassim experiment ($p < 0.05$ or $p < 0.01$) relative to the average of founder breeds. In UK, Gibb et al. (1993) using British Saanen, Boer × British Saanen and Anglo-Nubian male kids reported that kids of the British Saanen breed were heavier at 8 weeks and at slaughter than Boer × British Saanen which in turn weighed more than kids of the Anglo-Nubian breed. In Egypt, Anous and Mourad (1993) using Alpine and Rove breed and Alpine × Rove cross revealed that estimates of heterosis for body weights ranged from 7 to 27%. In another study of Barki, Zaraibi and Damascus breeds, and Zaraibi × Barki, and Damascus × Barki crosses, Abdelsalam et al. (1994) found that the estimates of heterosis in the Zaraibi × Barki cross were 24, 14 and 12% for body weights at birth, 56 days and market, respectively, while the corresponding estimates for the Damascus × Barki cross were 0, 2 and 4%. In Bangladesh, Mia et al. (1993) with Black Bengal, Barbari and Anglo-Nubian kids, and Barbari × Black Bengal found that estimates of heterosis were −11, 10 and −1% for body weights at birth, 6 and 12 months of age, respectively. In China, Zhou et al. (2001) reported that kids from Boer × Xuhuai goats exceeded local Xuhuai goats in body weight by 51 and 49% at birth, 55 and 51% at 2 months, 53 and 61% at 6 months, and 58 and 58% at 12 months, respectively. In other Chinese studies, crossing Boer goats with seven native breeds (Yonghong, 1999; Jiabi et al., 2003) indicate that F_1 crossbred kids were increased in birth weight, 4-month weight, 6-month weight, yearling weight and adult weight by 37.10, 49.70, 66.29, 77.85, and 68.41% in the males and by 41.62, 47.21, 60.03, 61.78, and 67.06% in the females, compared with those local breeds at the same age; i.e. Boer goats are playing an important role in improving local breeds in China.

In practice, positive and significant estimates of direct heterosis for growth traits (Table 5) indicate that the benefits of heterosis were realized after weaning when the favourable maternal common environmental effects are diminished. In Egypt, Mourad and Anous (1998) found significant heterotic effects for weight gain between 30 and 90 days of age in kids derived from the Alpine and Rove breeds. In general, estimates of direct heterosis reported here for growth traits (Table 5) were lower than those reported by Gebrelul et al. (1994), who reported estimates of 0.24, 1.9 kg and 19.8 g for birth weight, weaning weight and daily gain between birth and weaning, respec-

Table 5
Estimates of direct heterosis and their standard errors ($H^I \pm SE$) for growth traits in Jouf and Qassim experiments.

Trait	Jouf experiment			Qassim experiment		
	Units	SE	$H^I\%^a$	Units	SE	$H^I\%^a$
Body weight (kg)						
0 week	0.16*	0.05	4.8	0.31*	0.14	8.7
4 weeks	0.76*	0.06	8.7	0.52*	0.21	6.5
8 weeks	0.93*	0.07	7.1	1.39**	1.04	11.2
12 weeks	1.20*	0.09	7.6	1.48*	0.48	9.6
16 weeks	0.79*	0.10	4.2	1.44*	0.69	7.8
20 weeks	0.55NS	0.10	2.4	1.80*	0.81	8.6
24 weeks	1.39*	0.13	5.5	1.56*	0.46	6.7
Daily gain in weight (g)						
0–4 weeks	12.0*	3.0	6.7	14.0*	2.1	9.1
4–8 weeks	7.1*	2.0	4.3	14.1*	5.2	9.3
8–12 weeks	8.2*	3.1	5.9	17.2*	4.1	11.7
12–16 weeks	7.3*	2.2	4.8	15.1*	6.1	12.2
16–20 weeks	6.0NS	2.9	2.9	19.0**	2.2	14.5
20–24 weeks	9.2*	3.2	5.2	16.1*	1.1	12.3

NS, non-significant.
[a] $H^I\% = [H^I$ in units/(average of purebreds)] × 100.
* $P < 0.05$.
** $P < 0.01$.

tively, in cross kids between Alpines and Nubian breeds. El Fadili and Leroy (2001) reported low estimate of heterosis for weaning weight to be 0.03 kg in crosses between two indigenous Moroccan breeds. Recently, Mugambi et al. (2007) reported positive direct heterosis for birth weight (+0.05 kg), yearling weight (+0.36 kg) and post-weaning daily gains (+3.04 g/day) but the estimates were negative in pre-weaning traits.

Estimates of direct heterosis were significant for six carcass traits out of 11 traits ($p < 0.05$; Table 6). Pre-slaughter weight, hot carcass weight, and weights of head, fur, heart, and kidneys showed favourable positive estimates of direct heterosis, while the estimates for meat composition traits were mostly negative and non-significant. However, crossbreeding experiments carried out in goats indicated the presence of positive heterotic effects on carcass performance, while these experiments were associated with little improvements in meat composition traits (Yonghong, 1999; Jiabi et al., 2003). Ruvuna et al. (1992) in Kenya reported that Toggenburg and Anglo-Nubian sired kids were similar in slaughter weight and carcass composition, while pre-slaughter weight, hot and chilled carcass percentage favoured kids from Galla compared to East African dams by 2.3 kg and 3.2% when slaughtered at 14.7 months of age. In UK, Gibb et al. (1993) using British Saanen, Boer × British Saanen and Anglo-Nubian male kids reported that kids of the Anglo-Nubian breed produced significantly heavier carcasses (hot, cold and empty) than British Saanen kids. In USA, Johnson et al. (1995) found that kids of the Nubian × Florida native goats compared to Florida native and Spanish × Florida native goats had significantly heavier slaughter weight (22 kg versus 19 and 19.3 kg, respectively) and carcass weight (10.9 kg versus 9.5 and 9.6 kg, respectively). In Egypt, Mourad and Anous (1998) found significant heterotic effects for carcass yield in kids derived from the Alpine and Rove breeds.

Table 6
Estimates of direct heterosis and their standard errors ($H^I \pm SE$) for carcass and meat composition traits in Qassim experiment.

Trait	Estimate	SE	$H^I\%^a$
Carcass traits			
Pre-slaughter weight (kg)	1.35*	0.34	4.8
Hot carcass weight (kg)	0.8*	0.13	5.5
Dressing percent	1.15NS	0.32	2.4
Head weight (g)	125*	90	6.1
Fur weight (g)	93*	230	4.4
Viscera weight (g)	126NS	136	1.4
Heart weight (g)	62*	12	4.2
Liver weight (g)	13NS	34	0.5
Lungs weight (g)	12NS	52	0.2
Kidneys weight (g)	16*	3	6.2
Spleen weight (g)	12NS	92	2.6
Meat chemical composition			
Moisture (%)	−0.6NS	0.23	−0.8
Dry matter (%)	0.9NS	0.36	3.3
Crude protein (%)[b]	0.7NS	0.56	0.9
Ether extract (%)[b]	−0.45NS	0.64	−2.5
Ash content (%)[b]	−0.27*	0.05	−6.1

NS, non-significant.
[a] $H^I\% = [H^I$ in units/(average of purebreds)] × 100.
[b] Traits expressed on dry matter basis.
* $P < 0.05$.

3.3. *Maternal heterosis*

The estimates of maternal heterosis for most body weights in Jouf experiment were positive and significant ($p < 0.05$ or $p < 0.01$), ranging from 2.4 to 10.7% (Table 7). For daily weight gains, three estimates out of six were also significant ($p < 0.05$) and the estimates ranged from 2.4 to 8.4% relative to the mid-parents. Moderate estimates of maternal heterosis for some body weights and gains indicate that crossbred dams had moderate maternal heterosis in growth traits over their purebred dams. In this regard, crossing not only improves maternal environment, but it is expected to enhance milk production in the crossbred female parent, as well as growth performance of their progenies (Shrestha and Heaney, 2004).

Table 7
Estimates of maternal heterosis and their standard errors ($H^M \pm SE$) for growth traits in Jouf experiment.

Trait	Units	SE	$H^M\%$[a]
Body weight (kg)			
0 week	0.12*	0.05	3.6
4 weeks	0.93**	0.08	10.7
8 weeks	0.33NS	0.08	2.5
12 weeks	0.38NS	0.07	2.4
16 weeks	0.45NS	0.12	2.4
20 weeks	0.46*	0.20	4.0
24 weeks	0.98*	0.23	3.9
Daily gain in weight (g)			
0–4 weeks	15.1*	6.1	8.4
4–8 weeks	5.2NS	8.2	2.9
8–12 weeks	5.1*	2.3	3.5
12–16 weeks	16.0*	5.2	6.9
16–20 weeks	5.1NS	9.1	2.4
20–24 weeks	14.0*	6.2	5.7

NS, non-significant.
[a] $H^I\% = [H^I$ in units/(average of purebreds)] × 100.
* $P < 0.05$.
** $P < 0.01$.

Correspondingly, the heterosis exhibited in the crossbred parent and in their kids is of major economic importance. Gebrelul et al. (1994) found that estimates of maternal heterosis were 0.16 ± 0.09 kg for birth weight; 1.0 ± 0.4 kg for weaning weight; 1.4 ± 0.7 kg for 6 months weight and they concluded that body weight of single cross kids exceeded the contemporary kids of the purebred dam by 4–11% at birth, 8–17% at 10–12 weeks, 3–5% at 6 months of age. Mugambi et al. (2007) reported that estimates of maternal heterosis were negative for birth weight and post-weaning daily gains but they were positive for weaning weight and pre-weaning daily gains. Favourable effects of maternal heterosis in weaning and pre-weaning daily gains were expected because kids in this study were suckled and reared by their dams; and therefore pre-weaning growth and the associated weaning weight could be considered as direct indicator of the milk production and mothering ability of the dam.

4. Conclusions

Differences in direct additive effects between Aradi and Damascus were generally in favour of Damascus breed for growth and carcass traits, i.e. Damascus goats could be used in crossbreeding programs in Saudi Arabia and other countries of similar production environments.

Heterosis estimates obtained in this experiment are of considerable importance, particularly for growth and carcass components, while those estimates related to meat quality traits were of little importance.

Acknowledgement

The authors greatly acknowledge King Abdulaziz City for Science and Technology, Saudi Arabia, that granted this project (No.: ARP: 24-22) for six years (from 1/1/2006 to 1/1/2012).

References

Abdelsalam, M.M., Haider, A.E., Aboul-Naga, A.M., El-Kimary, I.S., Eissa, M., 1994. Improving performance of desert Barki kids by crossing with Zaraibi and Damascus goats. Egypt. J. Anim. Prod. 31, 85–97.

Al-Dobaib, S.N., Mehaia, M.A., Khalil, M.H., 2009. Effect of feeding discarded dates on milk yield and composition of *Aradi* goats. Small Rumin. Res. 81, 167–170.

Al-Saef, A.M., 2009. Genetic analysis for growth, carcass and meat composition traits in crossing program of Saudi Aradi with Damascus goats. J. Agric. Vet. Sci. 3, in press.

Anous, M.R., Mourad, M.M., 1993. Crossbreeding effects on reproductive traits of does and growth and carcass traits of kids. Small Rumin. Res. 12, 141–149.

AOAC, 1990. Official Methods of Analysis of the Association of Official Agricultural Chemists. Washington, DC.

Barillet, F., 2007. Genetic improvement for dairy production in sheep and goats. Small Rumin. Res. 70, 60–75.

Boldman, K.G., Kriese, L.A., Van Tassell, C.P., Kachman, S.D., 1995. A Manual for Use of MTDFREML. A Set Programs to Obtain Estimates of Variances and Covariance [DRAFT]. U.S. Department of Agriculture, Agricultural Research Service, USA.

Dickerson, G.E., PP 47 1992. (Manual for evaluation of breeds and crosses of domestic animals). Food and Agriculture Organization of the United Nations, Rome.

Dhanda, J.S., Taylor, D.G., McCosker, J.E., Murray, P.J., 1999. The influence of goat genotype on the production of Capretto and Chevon carcasses. 1. Growth and carcass characteristics. Meat Sci. 52, 355–361.

Dosari, M.N., Al-Hazab, A.A., Al-Haj, G.A., 1996. Nutritional and physiological studies to native goat breeds in Saudi Arabia. King Abdul Aziz City for Science Technology. Project AT-13-43.

El Fadili, M., Leroy, P.L., 2001. Estimation of additive and non additive genetic parameters for reproduction, growth, and survival traits in crosses between the Moroccan D'Man and Timahdite breeds. J. Anim. Breed. Genet. 118, 341–353.

Fahmy, M.H., Shrestha, J.N.B., 2000. Proceedings of the Seventh International Conference on Goats, France. Genetics for the improvement of goat meat production., 187–190.

Gebrelul, S., Sartin, L.S., Iheanacho, M., 1994. Genetic and non-genetic effects on growth and mortality of Alpine, Nubian and crossbred kids. Small Rumin. Res. 13, 169–176.

Gibb, M.J., Cook, J.E., Treacher, T.T., 1993. Performance of British Saanen. Boer × British Saanen and Anglo-Nubian castrated male kids from 8 weeks to slaughter at 28, 33 or 38 kg live weight. Anim. Prod. 57, 263–271.

Groeneveld, E., 2006. 'PEST Userĩs Manual. Institute of Animal Husbandry and Animal Behaviour, FAL, Germany.

Hirooka, H., Mukherjee, T.K., Panandam, J.M., Horst, P., 1997. Genetic parameters for growth performance of the Malayasian local goats and their crossbreds with the German (improved) Fawn goats. J. Anim. Breed. Genet. 114, 191–199.

Jiabi, P., Zegao, D., Taiyong, C., Jiyun, G., 2003. Improvement Effect of Crossbreeding Boar Goats and Sichuan Native Goats. Heifer Project International/China Office, Chengdu, Sichuan 610041, China.

Johnson, D.D., McGowan, C.H., Nurse, G., Anous, M.R., 1995. Breed type and sex effects on carcass traits, composition and tenderness of young goats. Small Rumin. Res. 17, 57–63.

Mavrogenis, G.A., Constantinou, A., Louca, A., 1984a. Environmental and genetic cause of variation in production traits of Damascus goats. I. Pre-weaning and post-weaning growth. Anim. Prod. 38, 91–98.

Mavrogenis, A.P., Constantinou, A., Louca, A., 1984b. Environmental and genetic causes of variation in production traits of Damascus goats. 2. Goat productivity. Anim. Prod. 38, 99–104.

Mia, M.M., Ali, A., Howlider, M.A.R., 1993. Growth performance of Black Bengal, Barbari. Anglo-Nubian and Barbari × Black Bengal goats. Indian J. Anim. Sci. 63, 1214–1215.

Mogensen, C.E., Andersen, M.J.F., 1973. Increased kidney size and glomerular filtration rate in early juvenile diabetes. Diabetes 22, 706–712.

Mourad, M., Anous, M.R., 1998. Estimates of genetic and phenotypic parameters of some growth traits in common African and Alpine crossbred goats. Small Rumin. Res. 27, 197–202.

Mugambi, J.N., Wakhungu, J.W., Inyangala, B.O., Muhuyic, W.B., Muasya, T., 2007. Evaluation of the performance of the Kenya Dual Purpose Goat composites: Additive and non-additive genetic parameters. Small Rumin. Res. 72, 149–156.

Ruvuna, F., Taylor, J.F., Okeyo, M., Wanyoike, M., Ahuya, C., 1992. Effects of breed and castration on slaughter weight and carcass composition of goats. Small Rumin. Res. 7, 175–183.

Salah, M.S., Bakkar, M.N., Mogawer, H.H., 1989. Body weight of Aradi goat kids in Saudi Arabia at different ages and affecting factors. J. King Saud Univ. Agric. Sci. 1, 17–24.

Sawaya, W.N., Safi, W.J., Al-Shalhat, A.F., Al-Mohammad, M.M., 1984. Chemical composition and nutritive value of goat milk. J. Dairy Sci. 67, 1655–1659.

Schafer, J.A., 2004. Renal water reabsorption: a physiologic retrospective in molecular era. Kidney Int. 66 (supl. 91), 520–527.

Shrestha, J.N.B., Heaney, D.P., 2004. Review of Canadian. Outaouais and Rideau Arcott breeds of sheep. 2. Crossbreeding, registration and subsequent release to the Canadian sheep industry. Small Rumin. Res. 55, 1–13.

Shrestha, J.N.B., Fahmy, M.H., 2007a. Breeding goats for meat production: a review (2). Crossbreeding and formation of composite population. Small Rumin. Res. 67, 93–112.

Shrestha, J.N.B., Fahmy, M.H., 2007b. Breeding goats for meat production: a review (3). Selection and breeding strategies. Small Rumin. Res. 67, 113–125.

Wolf, J., 1996. User's Manual for the Software Package CBE. Version 4. 0 (A universal program for estimating crossbreeding effects). Research Institute of Animal Production, Prague-Uhrineves, Czech Republic.

Wolf, J., Distl, O., Grosshan, T., Seeland, G., 1995. Crossbreeding in farm animals. V. Analysis of crossbreeding plans with secondary crossbred generations. J. Animal Breeding and Genetics 112, 81–94.

Yonghong, H., 1999. Utilization and Development of Boar Goats in China. Yangzhou University, Yangzhou, Jiangsu Province 225000, P.R. China.

Zhou, G.S., Chen, Q.L., Zhao, K.F., 2001. Hybridization test of Boer goat with Xuhuai goat. Chin. J. Anim. Sci. 37, 40–41.