11-5-2018

Influence of crossbreeding on meat goat doe fitness when comparing Boer F1 with base breeds in the Southeastern United States

Piush Khanal
Tennessee State University

Maria L. Leite-Browning
Tennessee State University

Richard Browning Jr.
Tennessee State University

Recommended Citation

P. Khanal, M.L. Leite-Browning, R. Browning "Influence of crossbreeding on meat goat doe fitness when comparing Boer F1 with base breeds in the Southeastern United States" J Anim Sci. 2019 Jan; 97(1): 78–89. https://dx.doi.org/10.1093%2Fjas%2Fsky421

Influence of crossbreeding on meat goat doe fitness when comparing Boer F_1 with base breeds in the Southeastern United States[1]

Piush Khanal,[2] Maria L. Leite-Browning, and Richard Browning, Jr.[3]

College of Agriculture, Tennessee State University, Nashville, TN 37209-1561

ABSTRACT: Understanding fitness level among various breeds is essential for sustainable meat goat production. Research on the relative fitness of Boer F_1 does and straightbred base breed has been limited. Meat goat does of various genotypes (Boer, Kiko, Spanish, Boer × Kiko reciprocal F_1 crosses, and Boer × Spanish reciprocal F_1 crosses) were studied to evaluate breed effects on doe fitness traits and the expression of heterosis over 7 production years. The herd was semi-intensively managed under humid subtropical pasture. Doe age affected ($P < 0.05$) various traits. Boer × Kiko does were heavier ($P < 0.05$) than Boer does at fall breeding, but Boer × Spanish does did not differ ($P > 0.05$) from Boer does for breeding weight. The body weights of Boer × Spanish and Boer × Kiko crosses did not differ ($P > 0.05$) from the weights of their respective Kiko and Spanish base cohorts at breeding, kidding, or weaning. Boer does had lower ($P < 0.05$) kidding rate (**KR**) and weaning rate (**WR**) than the other breeds and crosses. Boer × Kiko and Kiko were similar for KR and WR. Boer × Spanish and Spanish were also similar for KR and WR. However, the combined group of Boer F_1 does had lower ($P < 0.01$) KR and WR than the combined purebred biotype group of Kiko and Spanish does. Boer does weaned smaller ($P < 0.05$) litter sizes per doe exposed compared with Kiko, Spanish, Boer × Kiko, and Boer × Spanish does with the latter four doe breedtypes not differing from each other. The combined Boer F_1 doe group weaned smaller ($P < 0.05$) litter sizes per doe exposed than the combined purebred group of Kiko and Spanish does. Boer × Kiko dams had higher ($P < 0.05$) fecal egg counts at parturition than Kiko dams. Significant heterosis was observed for reproductive traits within each of the 2-breed diallels. Boer F_1 does exhibited reproductive output similar to or lower than Kiko and Spanish straightbred does and higher than Boer straightbred does.

Key words: Boer, crossbreeding, Kiko, meat goat, reproduction, Spanish

J. Anim. Sci. 2019.97:78–89
doi: 10.1093/jas/sky421

INTRODUCTION

The common breeds of meat goat in United States are Boer, Kiko, and Spanish. The Boer goat originated from South Africa and was developed to be a superior meat producer (Casey and Van Niekerk, 1988; Malan, 2000). The Kiko goat originated in New Zealand as a composite produced by crossing dairy sire breeds with feral does and selected for hardiness along with meat production (Batten, 2014). The Boer and Kiko were first imported by the United States in the early to mid-1990s to enhance the resident population of Spanish goats. The Spanish goat is landrace breed

[1]This research was supported by USDA funds provided to Tennessee State University through the Southern SARE (Grant LS13-254) and Evans-Allen programs. We express appreciation to M. Byars, J. Groves, E. Hayes, and various undergraduate students for technical assistance.

[2]Present Address: Department of Animal Science, North Carolina State University, Raleigh, NC

[3]Corresponding author: rbrowning@tnstate.edu

Received August 17, 2018.
Accepted November 2, 2018.

which evolved in the United States from goats delivered by Spanish explorers in the 1500s (Glimp, 1995). A common perception is that the Boer is the most productive meat goat breed and has thus been introduced to most regions of the world. Adequate research is required to find which breeds or crosses are better suited for a particular environment across a range of economically important traits. This is especially true for female fitness traits. Boer does had reduced fitness levels than Kiko and Spanish does in studies under humid, subtropical pasture conditions (Browning et al., 2011; Wang et al., 2017). Similar work is needed to assess Boer-cross does since the influx of Boer germplasm has led to a substantial number of Boer-influenced does in commercial herds. Limited research has been published on the comparative evaluation of Boer-cross and base breed does (Kimmés, 1992; Yonghong et al., 2001; Rhone et al., 2013, 2016). There is an absence of maternal heterosis estimates in the literature for female fitness in meat goats involving complete diallels. The objectives of the current study were to compare Boer F_1 does with straightbred Boer, Kiko, and Spanish base goats for female fitness traits and to generate heterosis estimates.

MATERIALS AND METHODS

Study Population

Data for reproductive performance and health were collected over 7 production years from does born and raised on the Tennessee State University (**TSU**) research station. The number of does and doe records by genotype are included in Table 1. The study does were produced from the mating of Boer, Kiko, and Spanish does to Boer, Kiko, and Spanish bucks over 4 yr (Browning et al., 2011; Wang et al., 2017). All of the Boer (n = 27), Kiko (n = 16), and Spanish (n = 15) sires produced straightbred and F_1 half-sib daughters in the study population. Doelings were raised as replacements without selection for performance and added to the breeding herd at 1.5-yr-old (Khanal et al., 2016). Early work on this study involving 2 yr of primiparous doe observations was published by Nguluma and coworkers (2013). Calendar year references correspond to the year of kidding in a fall breeding, spring kidding production year. Herd management protocols were approved by the TSU Animal Care and Use Committee.

Herd Management

The herd was semi-intensively managed on the TSU research station that is situated on river bottomland along Cumberland River (36°10′ N, 86°49′W) in Nashville, TN. The research station is in the humid subtropics at 183 m above the sea level and receives 1,222 mm of precipitation evenly distributed throughout the year. The herd foraged predominantly cool-season tall fescue (*Festuca arundinacea*) and warm-season bermuda grass (*Cynodon dactylon*). Other species of grasses, clovers, and broadleaf weeds were available in the pasture for grazing and browsing. Does were provided free-choice access to orchard grass hay (*Dactylis glomerata*) for winter consumption. From 2009 to 2014, nutrient supplementation followed the protocol of Wang et al. (2017). Supplementation in 2015 and 2016 was the same as in 2014 as the herd was fed the 16% CP commercial pellet (454 g/d) during the breeding season and whole cottonseed (*Gossypium hirsutum*; 22% CP and 85% TDN, as-fed basis; 262 g/d) during gestation and first 30 d of the lactation. Water and minerals were provided for free-choice access at all times.

Does were randomly assigned to different service sire breeds (Boer, Myotonic, Kiko, Savanna, and Spanish) in breeding pens for 30 to 45 d in

Table 1. Number of study does and doe records at each production period of observation

	Doe genetic group[1]						
Item	BB	KK	SS	BK	KB	BS	SB
Doe inventory							
Breeding	13	58	56	39	23	33	26
Kidding	3	49	47	30	19	23	21
Weaning	2	41	41	26	15	20	18
Production records							
Breeding	20	144	141	91	52	67	54
Kidding	4	111	112	61	37	44	35
Weaning	2	90	95	52	27	38	26

[1]First letter of doe genetic group designated sire breed of doe and second letter indicates dam breed of doe (B = Boer; K = Kiko; S = Spanish).

single-sire breeding pens. Service-sire breeds used each year were balanced across doe genotypes, but were not balanced across production years. Service sires were equipped with a marking harness to identify does mated. Kidding occurred between February and May. Kids were born on pasture with shelter provided. Kids at birth were weighed, tagged for unique identification, and recorded with dam identification. Kids were not vaccinated before weaning. Male kids were not castrated. Kids were not creep-fed in 2009 to 2013. One half of the kids were creep-fed from 2014 to 2016 (Hayes et al., 2016). Creep feeding assignments were balanced across dam age, dam breed, kid sex, service-sire breed, and litter size. All kids suckled dams until weaned at a contemporary group median age of approximately 90 d. Kids at weaning were weighed, dewormed, and vaccinated against *Clostridium perfringens* Type C and D, tetanus, and pneumonia. The herd was routinely checked every day for well-being status. Does expressing clinical symptoms of endoparasite infestation (e.g., scours, mandibular edema, and anemia) were orally treated with an anthelmintic. Other health issues such as lameness were also treated upon observation. Does exited the herd primarily because of death or failure to wean a kid twice. Does were vaccinated annually against pneumonia and clostridial diseases 1 mo before parturition and were dewormed at parturition.

Data Collection

Doe body weights (**BW**), fecal egg count (**FEC**), and packed cell volume (**PCV**) were determined in each year at breeding, kidding, and weaning. Doe reproductive traits study included kidding rate (**KR**), weaning rate (**WR**), litter size at kidding (**LSK**), LS at weaning (**LSW**), total litter weight at birth (**LWK**), and total LW at weaning (**LWW**). Fertility (i.e., KR) was measured based on the does kidding per does exposed and was coded "0" if a doe did not kid and "1" if a doe kidded. Similarly, the proportion of does weaning at least 1 kid per doe exposed was treated as a binary trait. Stillborns (kids born dead) were excluded from LSK and LWK determinations. Kid alive but rejected by dams, orphan, and hand-raised kids were excluded from LSW values. Survival rate (**SR**) was measured based on doe inventories at the start (1 September) and end (31 August) of a production year. Doe survival was coded as "1" if still in the herd by 31 August and "0" if a doe exited the herd by 31 August. Does exited the herd via mortality or being culled after failure to wean a kid for the second time. FEC was determined for does to assess gastrointestinal parasite loads. For each fecal sample, 2 g of sample were dissolved in 28-mL saturated salt solution. After filtration, the mixed fecal sample solution was transferred to a gridded 2-chamber McMaster slide for counting eggs. The McMaster technique had a detection limit of 50 eggs/g (Coles et al., 2006). Blood samples were drawn from the jugular vein, stored in EDTA tubes, and transported to the laboratory for PCV determination. Processing for PCV followed the procedure detailed by Wang et al. (2017).

Statistical Analysis

Doe weight, litter weight, FEC, PCV, and production efficiency data were analyzed using MIXED model procedures for repeated measures of SAS (SAS Inst. Inc., Cary, NC). FECs were transformed by $\log_{10}$ (egg count + 1) for statistical operation and back-transformed to geometric means for presentation. Doe breed, doe age, and interaction of the 2 were the fixed effects. Service-sire breed was included as a fixed effect in the models for LWK and LWW. Production year and doe nested in doe breed were the random effects.

Various analyses were applied to different doe populations. The breeding population included all does in the herd during fall breeding; this is sometimes referred to as the whole-herd population. The kidding population included only does with successful parturitions. The weaning population included only does weaning at least 1 kid. To balance the doe age groups, does 6 yr and older were combined as a single group (age 6+) when analyses were based on the breeding and kidding doe populations. Does 5 yr and older were combined as a single group (age 5+) when analyses were based on weaning doe population. Boer goats were removed from analyses of kidding and weaning populations because of insufficient sample size.

The proportions of does in the fall breeding herd that kidded (KR), weaned kids (WR), and survived (SR) until the end of a production year were analyzed using GLIMMIX model procedures of SAS using binomial distribution. Litter size at kidding and LSW were analyzed using GLIMMIX model procedures of SAS using Poisson distribution.

Linear contrasts were run within the Boer–Kiko and Boer–Spanish diallels to estimate heterosis effects within each 2-breed diallel similar to those used by Browning and Leite-Browning (2011) as described by Riley et al. (2007) using MIXED model procedures of SAS. Heterosis estimates were generated for whole-herd traits that included all does exposed (doe body weight at breeding, KR, WR, SR, FEC and PCV at breeding, LSW, and LWW). Heterosis for whole-herd analysis was based on the variance of the reciprocal crossbred doe mean from the straightbred doe mean within each 2-breed diallel.

The Tukey–Kramer mean separation test was used for comparing the least square means ($\alpha = 0.05$) for all doe traits. Probability levels less than 0.05 for the *F*-statistic were regarded as indicating a significant difference.

RESULTS AND DISCUSSION

Doe Body Weight

Doe breed × doe age did not affect ($P > 0.05$) doe body weight at any of the measurement times. Age of doe and breed were important sources of variations ($P < 0.001$) affecting breeding, kidding, and weaning doe weights. Does generally increased in body weight with advancing age (Table 2). This result agreed with Browning et al. (2011). Wilson and Light (1986) also suggested that young primiparous dams may be lighter than the general doe population which could adversely affect their reproductive outcomes.

Doe weights in the current study were generally lower than in the earlier study at this location. Does in the earlier study of Browning et al. (2011) received a higher level of supplementation than in the current study. Additionally, many does in the earlier study were acquired from outside seedstock herds developed under higher management levels. Mean Boer doe weight was lower here than at some other study locations (Greyling et al., 2004; Menezes et al., 2016), but similar to other study sites (Kamarudin et al., 2011; Abd-Allah et al., 2015). Kiko, Spanish, and Boer × Spanish doe weights reported in this study were lower than at other study locations (Rhone et al., 2013; Batten, 2014). The lower weight of does in the current study than at some other locations might be due to differences among management environments for doe development and production.

Kiko does were heavier than Spanish does at all 3 measurement points in agreement with Browning et al. (2011). Boer × Kiko does were heavier ($P < 0.05$) than Boer does but Boer × Spanish does did not differ from Boer does at breeding. This may be related to the observation that Boer–Kiko combination generated a higher level of heterosis for weaning weight than the Boer–Spanish combination (Browning and Leite-Browning, 2011). Boer F_1 does did not differ from the respective non-Boer parental breeds (i.e., Kiko and Spanish does). Rhone et al. (2013) reported that Boer × Spanish does were heavier than Spanish does. Similarly, Jiabi et al. (2001) reported that crossing of Boer with several local breeds in China increased mature doe body weights. The contrast between this study and the 2 cited reports for doe weight may be partly because the cited studies lacked an assessment of the reciprocal cross does by not having daughters of Boer dams. Earlier work here (Browning and Leite-Browning, 2011) indicated that Boer had a significantly negative maternal effect on weaning weight. Boer × Spanish reciprocal-cross F_1 does were lighter ($P < 0.05$) than Boer × Kiko reciprocal-cross F_1 does at each time point, probably reflecting the heavier weight of the Kiko base breed compared with the Spanish base.

Table 2. Effect of doe breed and doe age on doe body weight at different production time points

	Doe weight, kg		
Class	Breeding	Kidding	Weaning
Breed of doe			
Boer	32.47 ± 1.75^{c}	–	–
Kiko	38.39 ± 1.20^{ab}	37.76 ± 1.29^{a}	35.54 ± 0.96^{ab}
Spanish	33.29 ± 1.20^{c}	33.86 ± 1.29^{b}	32.70 ± 0.95^{c}
Boer × Kiko	38.58 ± 1.20^{a}	38.00 ± 1.30^{a}	37.48 ± 0.95^{a}
Boer × Spanish	35.39 ± 1.21^{bc}	34.70 ± 1.32^{b}	34.74 ± 1.00^{bc}
Age of doe, yr			
2	29.50 ± 1.16^{e}	29.44 ± 1.23^{d}	30.71 ± 0.81^{d}
3	32.66 ± 1.20^{d}	34.19 ± 1.31^{c}	34.18 ± 0.92^{c}
4	34.86 ± 1.19^{c}	36.85 ± 1.29^{b}	36.03 ± 0.88^{b}
5	38.45 ± 1.21^{b}	38.05 ± 1.31^{b}	39.53 ± 0.88^{a}
6+	42.66 ± 1.29^{a}	41.86 ± 1.41^{a}	–

[a–e]LSmeans (±SE) within a class and trait not sharing common superscript differ ($P < 0.05$).

Whole-Herd Reproductive and Survival Rates

Only doe breed ($P < 0.001$) affected KR. Fertility (i.e., KR) was lower ($P < 0.01$) for Boer does than for Spanish and Kiko does (Table 3), in agreement with Browning et al. (2011) and Wang et al. (2017). Boer does also had lower KR than both Boer-cross groups (Table 3). The KR of Boer F_1 groups did not differ ($P > 0.05$) from their respective straightbred Kiko and Spanish cohorts which agreed with Rhone et al. (2013).

Doe age and doe breed influenced ($P < 0.01$) WR. Five-year-old does had lower ($P < 0.01$) WR than 3- and 4-yr-old does (Table 3). Two- and 6+-yr-old does did not differ from the extremes. This response differed from that of Browning et al. (2011) where doe age did not affect WR. Boer doe had lower ($P < 0.05$) WR than Kiko and Spanish (Table 3) which agreed with Browning et al. (2011) and Wang et al. (2017). Boer does also had lower ($P < 0.01$) WR than Boer × Kiko and Boer × Spanish does (Table 3). The WR of Kiko and Spanish straightbred does did not differ from their Boer-cross contemporaries. The lower WR of Boer is most likely related to their lower expressed level of fertility.

Boer does were removed from the dataset and the data were reanalyzed for KR and WR. Doe genotype was analyzed with Kiko and Spanish does merged to form 1 straightbred group. Boer × Kiko and Boer × Spanish does were merged to form 1 Boer F_1 crossbred group. In this analysis, doe age × genotype was not significant for either trait. Genotype influenced ($P < 0.01$) KR and WR. The straightbred doe group had higher ($P < 0.01$) KR and WR (82.9 ± 8.7% and 69.5 ± 8.3%) than the Boer F_1 group (71.8 ± 12.3% and 58.9 ± 9.2%).

Several sheep studies have looked at fertility in straightbred vs. crossbred ewes with mixed outcomes depending on the breeds and crosses involved (Boujenane and Bradford, 1991; Fogarty et al., 2000; Boujenane et al., 2003; Barbato et al., 2011). In goats, studies comparing doe breeds for fertility are in short supply and structured studies involving crossbred does seem to be even more difficult to find in the scientific literature. Literature related to genetic comparisons for whole-herd WRs among doe breeds and their crosses is also scarce. Boer F_1 does in the current evaluation showed higher fertility and WR than Boer does but did not differ from the other individual base breeds. However, the Boer-cross does as a single genetic group had lower KR and WR than the base breeds when Kiko and Spanish were grouped as a single purebred biotype.

Doe breed and doe age affected ($P < 0.05$) doe SR. Does from 3-yr-old does had higher ($P < 0.05$) SR than does 6+ yr of age (Table 3). Doe SR of 2-, 4-, and 5-yr-old does were intermediate and not differing from either extreme. It was not surprising that older does were at higher risk of exiting the herd via mortality or involuntary culling than younger does.

Survival rate for Boer does was lower ($P < 0.05$) than that of Kiko does (Table 3). Survival rate of the Boer does was higher than their reproductive rates. This coupled with the small size of the Boer population led to the Boer doe group not statistically separating from Spanish and the 2 Boer-cross doe groups. Boer does had lower SR than Kiko and Spanish does in 2 earlier reports from this research station (Browning et al., 2011; Wang et al., 2017). The SR of Boer × Kiko and Boer × Spanish does were closely aligned with their respective non-Boer base cohorts. The data were reassessed excluding the Boer does. Statistical nonsignificance remained among the remaining 4 doe groups. Similar to the

Table 3. Effect of doe breed and doe age on whole herd reproductive and survival rates

Class	Kidding rate, %	Weaning rate, %	Survival rate, %
Doe breed			
Boer	18.4 ± 12.7[b]	11.1 ± 9.7[b]	53.2 ± 11.8[b]
Kiko	81.7 ± 9.6[a]	67.1 ± 15.4[a]	84.8 ± 3.3[a]
Spanish	84.9 ± 8.3[a]	73.7 ± 13.5[a]	79.1 ± 3.8[ab]
Boer × Kiko	73.5 ± 12.4[a]	60.7 ± 13.5[a]	78.1 ± 3.9[ab]
Boer × Spanish	70.9 ± 13.2[a]	61.0 ± 16.6[a]	79.1 ± 4.1[ab]
Doe age			
2	67.8 ± 13.8	49.4 ± 17.5[ab]	77.0 ± 3.6[ab]
3	75.8 ± 12.2	64.1 ± 16.7[a]	84.9 ± 4.8[a]
4	75.6 ± 12.8	72.7 ± 14.9[a]	75.8 ± 5.2[ab]
5	48.6 ± 16.9	32.7 ± 16.3[b]	76.8 ± 5.8[ab]
6+	65.5 ± 15.4	43.4 ± 18.2[ab]	61.9 ± 6.7[b]

[a,b]LSmeans (±SE) within a class and trait not sharing common superscript differ ($P < 0.05$).

current study, Rhone et al. (2013) reported no difference in survival between Spanish and Boer × Spanish does.

Litter Characteristics at Parturition

Litter traits at kidding were only assessed with the population of does that kidded. Prolificacy (i.e., LSK) was not affected by a doe age × doe breed interaction. Doe age influenced LSK ($P < 0.05$; Table 4). The only doe-age groups that differed were 3- and 6+-yr-old, with the latter having more kids on average. Zhang et al. (2009) and Browning et al. (2011) reported that the LSK for does was lower for 1- to 2-yr-old and higher for 4- and 5-yr-old dams. Rhone et al. (2013) suggested an increase of LSK from 2- to 9-yr-old does. Breed of doe did not significantly affect LSK. Previous studies at this location also failed to find differences in LSK between Kiko and Spanish does (Browning et al., 2011; Wang et al., 2017). Several other studies similarly found that LSK in crossbred does was not improved over that in straightbred does (Wilson and Murayi, 1988; Karua and Banda, 1994; Montaldo et al., 1995). Although Rhone et al. (2013) reported no difference between Boer x Spanish and Spanish for LSK in agreement with the current study, 2 other reports indicated that Boer-cross does had smaller LSK than the non-Boer base local doe breeds (Kimmés, 1992; Yonghong et al., 2001). Few studies have reported an effect of doe breed or breed cross on LSK (Meza-Herrera et al., 2014). There is an interest in exploiting possible genetic differences in prolificacy to enhance meat goat productivity (Maitra et al., 2014; El-Tarabany et al., 2017). However, the current study along with the majority of others in the literature suggests that breed differences for this trait are not common.

Table 4. Effect of doe breed and doe age on litter traits at parturition in meat goat does

Class	Litter size, kids	Litter weight, kg
Breed of doe		
Kiko	1.68 ± 0.09	3.90 ± 0.58^{ab}
Spanish	1.60 ± 0.08	3.45 ± 0.58^{b}
Boer × Kiko	1.65 ± 0.09	4.09 ± 0.58^{a}
Boer × Spanish	1.54 ± 0.09	3.68 ± 0.58^{ab}
Doe age		
2	1.57 ± 0.08^{ab}	3.07 ± 0.58^{c}
3	1.47 ± 0.09^{b}	3.61 ± 0.60^{bc}
4	1.59 ± 0.09^{ab}	3.76 ± 0.59^{bc}
5	1.64 ± 0.10^{ab}	3.87 ± 0.60^{ab}
6+	1.83 ± 0.11^{a}	4.58 ± 0.60^{a}

$^{a–c}$LSmeans (±SE) within a class and trait not sharing a common superscript differ ($P < 0.05$).

Litter weight at kidding was not affected by a doe age × doe breed interaction or service-sire breed. Doe breed and doe age significantly influenced ($P < 0.001$) LWK (Table 4). The LWK of 2-yr-old does was lower than for does aged 5 yr and older. Does aged 6 yr and older had heaver LWK that the 3 youngest doe groups (Table 4). In general, LWK increased with dam age. Similarly, Rhone et al. (2016) reported that LWK continued to increase with advancing doe age, whereas Browning et al. (2011) did not find a significant increase of LWK in does from 3 yr of age onward.

Spanish did not differ from Kiko does for LWK which agreed with past studies (Browning et al., 2011; Rhone et al., 2016). Boer × Kiko did not differ from Kiko does for LWK and Boer × Spanish does did not differ from Spanish (Table 4). In general, the Boer maternal influence did not affect LWK. The LWK in F_1 does was higher than in straightbred does in a 2-breed study (Tsukahara, 2008) but not an earlier study involving several goat breeds (Montaldo et al., 1995). Litter traits at parturition represent both the end point for in utero conceptus development and the starting point for preweaning kid growth and development. As such, the litter traits at kidding can be used to assess if any differences in the uterine environment among maternal genotypes or litter types may exist that could affect postnatal offspring performance and warrant further inquiry (Rhind et al., 2001; Du et al., 2010; Pillai et al., 2017).

Litter Characteristics at Weaning

Doe age × doe breed and doe age as a main effect were not important sources of variation for LSW within the 3 populations evaluated. There was no breed influence ($P > 0.05$) on LSW based in the kidding and weaning populations (Table 5). Within the breeding population, Boer had smaller ($P < 0.05$) LSW than Kiko and Spanish (Table 5) which agreed with Browning et al. (2011). Boer does also had smaller ($P < 0.05$) LSW than Boer × Kiko and Boer × Spanish. This was likely because Boer does exhibited low fertility.

The doe breed × doe age interaction and service-sire breed did not influence ($P > 0.05$) LWW. Dam age influenced ($P < 0.05$) LWW (Table 6). Three- and 4-yr-old does had heavier ($P < 0.05$) LWW than 2- and 6+-yr-old does based on breeding population. Two-year-old does had lighter ($P < 0.05$) LWW than 4-yr-old does within kidding

Table 5. Effect of doe breeds and doe age on litter size at weaning by doe population

Class	Litter size, n kids		
	Breeding population	Kidding population	Weaning population
Breed of doe			
Boer	0.16 ± 0.08[b]	–	–
Kiko	0.94 ± 0.08[a]	1.17 ± 0.14	1.34 ± 0.15
Spanish	0.92 ± 0.08[a]	1.13 ± 0.14	1.26 ± 0.14
Boer × Kiko	0.78 ± 0.07[a]	1.09 ± 0.13	1.19 ± 0.14
Boer × Spanish	0.71 ± 0.08[a]	1.02 ± 0.13	1.15 ± 0.14
Doe age[1]			
2	0.55 ± 0.06	1.01 ± 0.12	1.17 ± 0.14
3	0.55 ± 0.08	1.09 ± 0.16	1.21 ± 0.16
4	0.67 ± 0.09	1.20 ± 0.16	1.34 ± 0.17
5	0.66 ± 0.09	1.06 ± 0.15	1.20 ± 0.14
6+	0.56 ± 0.09	1.14 ± 0.17	–

[1]For the weaning population, age 5 includes all does of age 5 and older (i.e., 5+).

[a,b]LSmeans (±SE) within a class and trait not sharing a common superscript differ ($P < 0.05$).

Table 6. Effect of doe breed and age on litter weight at weaning by doe population

Class	Litter weight, kg		
	Breeding population	Kidding population	Weaning population
Breed of doe			
Boer	3.34 ± 2.93[b]	–	–
Kiko	13.90 ± 1.90[a]	18.20 ± 1.69	22.22 ± 0.99[a]
Spanish	13.04 ± 1.90[a]	16.54 ± 1.69	19.15 ± 0.98[b]
Boer × Kiko	11.79 ± 1.89[a]	17.39 ± 1.72	20.98 ± 1.04[ab]
Boer × Spanish	10.22 ± 1.93[a]	15.44 ± 1.79	18.10 ± 1.10[b]
Doe age[1]			
2	8.05 ± 1.93[b]	13.41 ± 1.67[b]	17.41 ± 0.92[b]
3	11.89 ± 2.17[a]	17.55 ± 1.96[ab]	20.57 ± 1.24[ab]
4	13.40 ± 2.11[a]	19.56 ± 1.85[a]	21.02 ± 1.08[a]
5	9.64 ± 2.14[ab]	17.73 ± 1.97[ab]	21.38 ± 1.03[a]
6+	9.32 ± 2.18[b]	16.23 ± 2.01[ab]	–

[1]For the weaning population, age 5 includes all does of age 5 and older (i.e., 5+).

[a–c]LSmeans (±SE) within a class and trait not sharing a common superscript differ ($P < 0.05$).

population. Two-year-old does also had lighter ($P < 0.05$) LWW than does aged 4 yr and older for the weaning population. This study generally agrees with past reports from this location in that litter weaning traits improve in does as they advanced past 2 yr of age (Browning et al., 2011; Wang et al., 2017).

Based on breeding population, Boer does had lighter ($P < 0.05$) LWW than the other 4 doe genotypes with the other 4 not differing from each other. The lighter LWW of Boer does agreed with Browning et al. (2004) and Browning et al. (2011). This was probably closely tied to the lower LSW for the Boer does under the low-input management conditions.

Boer does were removed from the dataset and the data were reanalyzed for LSW and LWW for the breeding population. As with KR and WR, doe genotype was analyzed with Kiko and Spanish does combined into 1 straightbred group. Boer × Kiko and Boer × Spanish does were combined into 1 Boer crossbred group. Doe age × genotype was not significant for either trait. Genotype affected ($P < 0.01$) LSW and LWW. The group of straightbred does had higher ($P < 0.01$) values than the Boer crossbred group for LSW (0.91 ± 0.12 vs. 0.73 ± 0.10 kids weaned/doe exposed) and LWW (12.87 ± 1.36 vs. 10.39 ± 1.45 kg weaned/doe exposed).

Litter weaning traits of Boer does within the kidding and weaning populations could not be compared in this study because of their low SR and KR. In a series of sheep studies involving various ewe breeds, separation among straightbred and crossbred ewes was evident for weaning litter traits (Boujenane and Bradford, 1991; Boujenane and Kansari, 2002; Boujenane et al., 2003). Straightbred base ewe breeds differed, crossbred ewes commonly exceeded the inferior base breed, and crossbred ewes may or may not have differed from the superior base breed. Similar studies in does involving multiple goat breeds and breed crosses to measure comparative weaning litter traits were not readily available in the literature.

Litter size and litter weight at weaning are important economic traits in meat goats. They are influenced by doe fertility, mothering ability, and the ability of does to stay healthy. The levels of whole-herd litter traits at weaning in this study were lower than in the earlier study for the 3 straightbred doe groups (Browning et al., 2011) when does were on a higher level of supplementation. The most recent national survey of the U.S. goat industry indicated that kid crop born was 1.03 kids/doe across 1.26 million does (USDA-NASS, 2018). A lower kid crop weaned would be expected in the surveyed national inventory. The LSW in this study, although lower than in the earlier study from this lab (Browning et al., 2011), seemed generally reflective of the national level of doe reproductive output and may reflect lower management levels in commercial meat goat production systems.

The poor performance of Boer does in this and previous studies (Browning et al., 2004, 2011; Wang et al., 2017) suggested that the reproductive output of Boer F_1 does would not approach the levels of non-Boer base breeds. Boer F_1 does showed weaning output similar to or lower than their non-Boer base contemporaries. These are important outcomes to consider since a sizeable proportion of U.S. commercial meat goat does are Boer-influenced. Observations that infusion of Boer germplasm into the doe herd through crossbreeding did not improve doe performance were noteworthy because large-scale Boer importations were expected to make sweeping improvements in meat goat fitness and other aspects of herd performance (Erasmus, 2000; Malan, 2000), including that of the landrace Spanish goat in the United States. Boer germplasm did not improve the reproductive merits of the Kiko or Spanish populations. Ironically, crossbreeding with Kiko or Spanish dramatically enhanced reproductive performance of the Boer population.

Fecal Egg Count and Packed Cell Volume

FECs were not affected by an interaction of doe breed × doe age or doe age within any of the population datasets (Table 7). Doe breed affected ($P < 0.05$) FEC in the kidding population. The Boer × Kiko does had higher kidding FEC than Kiko-straightbred does (Table 7). The increased FEC for Boer × Kiko does compared with Kiko does is probably related to the tendency for higher FEC values in lactating Boer does. Spring kidding is when FEC values are the greatest because of the noted periparturient rise in endoparasitism (Baker et al., 1998; Wang et al., 2017). Wang et al. (2017) reported higher FEC for Boer does than for Kiko and Spanish does. Browning et al. (2011) reported higher rates of clinical endoparasitism for Boer does than for Kiko and Spanish does. In agreement with the current study, 2 recent reports from this location (Goolsby et al., 2017; Wang et al., 2017) reported no differences between Kiko and Spanish does for FEC.

PCV was not affected by interaction between doe breed and doe age within any of the population

Table 7. Effect of doe breed and doe age on fecal egg count[1] at different production time points

Class	Fecal egg count, eggs/g		
	Breeding	Kidding	Weaning
Breed of doe			
Boer	451	–	–
Kiko	170	1151[b]	890
Spanish	235	1192[ab]	837
Boer × Kiko	234	1795[a]	870
Boer × Spanish	270	1243[ab]	650
Doe age[2]			
2	245	1168	824
3	300	1119	953
4	294	1308	696
5	194	1512	765
6+	272	1565	–

[1]Geometic means.

[2]For the weaning population, age 5 includes all does of age 5 and older (i.e., 5+).

datasets. Only doe age affected ($P < 0.05$) PCV (Table 8). Wang et al. (2017) reported lower PCV for Boer does than for Kiko and Spanish does. Lack of difference in PCV between Boer and other base breeds in the breeding population in this study might be because of the lower number of Boer does in this study. In addition, the Boer does were only included in the assessment of FEC and PCV during fall breeding test period when endoparasite burden would be low when compared with the spring kidding and summer weaning periods (Wang et al., 2017). Similar FEC and PCV among Boer-cross does and their non-Boer parental breeds suggested that crossbreeding was effective in diluting the negative effect of Boer germplasm on endoparasitism. The PCV values decreased with increasing dam age in agreement with Wang et al. (2017) and with the report of Kaplan et al. (2004) in which FAMACHA score increased with doe age. FAMACHA scores (a system of classifying eye color to detect endoparasite-induced anemia in small ruminants; Kaplan et al., 2004) are negatively correlated with PCV.

Selecting and using genetically resistant goat breeds suitable to the particular environment could be an effective way to reduce endoparasitic loads, particularly since anthelmintic use is becoming a less reliable option for meat goat managers (Goolsby et al., 2017). Problems may arise if introduced goat breeds exhibit heightened sensitivity to endoparasites in a given production environment. It is not clear in the literature if crossbreeding is an effective genetic approach to reduce endoparasitism in doe herds. Few studies have been published where maternal breeds and their crosses have been compared for FEC and PCV, none were found for meat goats. In 3 sheep studies where unimproved, landrace-type ewe breeds had lower FEC than improved, commercial-type ewe breeds, the crossbred ewes had FEC similar to the landrace base–breed ewes (Yazwinski et al., 1979; Amarante et al., 1999), whereas the crossbred ewes had FEC similar to commercial base–breed ewes in the third study (Baker et al., 1999). The crossbred does in the current study followed the segregation of the former two studies with FEC similar to the better base doe breeds. Crossbred F_1 ewes did not differ from purebred ewes for PCV (Goossens et al., 1999), in agreement with this doe study. It appears that if lowering FEC and increasing PCV are herd objectives, producing crossbred does would not be advantageous over maintaining straightbred does of a relatively parasite-tolerant breed.

Heterosis Estimates

Heterosis is a benefit of crossbreeding that improves performance in hybrid livestock. It is generally thought that fitness traits express higher levels of heterosis than other traits. Heterosis has been well studied in breeding ewes (Nitter, 1978; Long et al., 1989; Bittante et al., 1996). Meat goat does have not been studied to a great extent for heterosis in mature weights or breeding herd fitness traits (Shrestha and Fahmy, 2007). The current study may be the first to do so with complete diallels for doe assessment. In the current population, heterosis for doe weight at breeding was significant for both Boer F_1 crosses (Table 9). Relative heterosis for breeding doe weight was slightly higher than the mean of values reviewed for breeding ewes (Nitter, 1978), lower than observed in breeding ewes by Gallivan et al. (1987), and higher than relative

Table 8. Effect of doe breed and doe age on packed cell volume at different production times

Class	Packed cell volume, %		
	Breeding	Kidding	Weaning
Breed of doe			
Boer	21.42 ± 1.85	–	–
Kiko	24.73 ± 1.06	23.12 ± 0.60	19.90 ± 1.04
Spanish	23.61 ± 1.06	22.52 ± 0.60	19.56 ± 1.03
Boer × Kiko	23.58 ± 1.06	22.18 ± 0.62	18.93 ± 1.07
Boer × Spanish	22.49 ± 1.09	22.59 ± 0.67	19.57 ± 1.14
Doe age[1]			
2	24.12 ± 1.14	25.11 ± 0.62[a]	20.67 ± 1.10[a]
3	23.13 ± 1.12	23.90 ± 0.61[ab]	20.36 ± 1.10[a]
4	23.33 ± 1.09	22.58 ± 0.56[bc]	18.88 ± 1.03[ab]
5	22.27 ± 1.11	21.22 ± 0.61[c]	18.04 ± 0.99[b]
6+	22.98 ± 1.14	20.19 ± 0.66[c]	–

[1]For the weaning population, age 5 includes all does of age 5 and older (i.e., 5+).

[a–c]LSmeans (±SE) within a class and trait not sharing a common superscript differ ($P < 0.05$).

Table 9. Heterosis estimates (±SE) for whole-herd doe traits within 2-breed diallels

Trait	Boer–Kiko		Boer–Spanish	
Breeding weight, kg	3.56 ± 1.28*	(9)	3.21 ± 1.21*	**(8)**
Kidding rate, %	19 ± 6*	(48)	16 ± 7*	**(35)**
Weaning rate, %	16 ± 7*	(54)	17 ± 7*	**(41)**
Survival rate, %	6 ± 5	(15)	11 ± 6	**(20)**
Litter size weaned, kids/doe exposed	0.23 ± 0.12*	(42)	0.18 ± 0.12	**(31)**
Litter weight weaned, kg/does exposed	6.98 ± 3.76*	(37)	4.41 ± 3.48	**(25)**
Fecal egg count, eggs/g	−0.07	(−25)	−0.19	**(−21)**
Packed cell volume, %	0.84 ± 1.02	(−2)	0.53 ± 1.04	**(0)**

*$P < 0.05$.

Value in parentheses is relative heterosis (i.e., the percent deviation of the reciprocal cross mean from the mean of the base breeds).

weaning weight heterosis previously observed in this study herd for Boer-cross kids (Browning and Leite-Browning, 2011).

Heterosis levels for doe fertility (i.e., KR) and whole-herd reproductive output at weaning (WR and litter traits at weaning) were high and significant (Table 9) for the Boer–Kiko F_1 reciprocal cross. Heterosis levels for reproductive traits were also high for the Boer–Spanish F_1 reciprocal cross, but only fertility and WR tested significant (Table 9). Nasrat et al. (2016) observed significant heterosis in LWW for only 1 of 4 two-breed crosses of ewes.

Relative heterosis levels (25% to 48%) for reproductive traits in this study were higher than most observations in ewes (Nitter, 1978; Long et al., 1989), but similarities existed between the current doe study and other ewe studies for whole-herd litter trait relative heterosis levels (Fogarty et al., 1984; Gallivan et al., 1987; Bittante et al., 1996). Anous and Mourad (1993) reported relative heterosis of 4% for fertility in goats; however, the 2 base breeds had identical fertility rates and one of the reciprocal doe crosses was absent from the study. No heterosis levels were significant for health traits (doe survival rate, FEC, and PCV) in either breed cross (Table 9); however, the relative heterosis was numerically substantial for survival rate and FEC.

Heterosis seemed to enhance the performance of Boer F_1 does, especially when compared with Boer-straightbred does. Caution is noted because of the small sample size of Boer doe population, but the research herd breeding plan was such that each breed and cross had equal opportunity to contribute female offspring to this study. Boer does simply demonstrated poor fitness from breeding and doeling production (Browning et al., 2011; Wang et al., 2017) to doeling development and entry into this study (Khanal et al., 2016). Heterosis likely contributed to the lack of a substantial decline in reproductive performance to weaning for Boer F_1 does when compared with their non-Boer base breeds.

In summary, Boer F_1 does exhibited fitness levels similar to or lower than Kiko and Spanish base does and substantially higher than Boer base does. This study further demonstrated lower fitness levels of Boer does than for Kiko and Spanish does. Spanish goats and native goat types globally have been generally devalued by many in industry and academia because of perceived inferiority as meat producers leading to widespread crossing with Boer goats. This is typical when a new, exotic breed is made available to improve or replace a local landrace stock. Under the prevailing conditions of this study, no benefit was evident from using Boer F_1 does instead of Spanish- or Kiko-straightbred base does for improved reproductive output. Improvements in Boer F_1 does over Boer-straightbred does in this study demonstrated the ability of crossbreeding to enhance reproductive traits in meat goats. It helps managers to know the relative trait values of the base breeds to be crossed to determine if the desired improvements are possible within the production environment.

LITERATURE CITED

Abd-Allah, S., R. Salama, M. I. Mohamed, M. M. Mabrouk, R. I. El-Kady, A. I. Kadry, and S. M. Ahmed. 2015. A comparative study on reproductive and productive performance of Boer and Baladi goats raised under similar environmental conditions in Egypt. Int. J. Chem. Tech. Res. 8:225–236.

Amarante, A. F., T. M. Craig, W. S. Ramsey, N. M. El-Sayed, A. Y. Desouki, and F. W. Bazer. 1999. Comparison of naturally acquired parasite burdens among Florida native, rambouillet and crossbreed ewes. Vet. Parasitol. 85:61–69. doi:10.1016/S0304-4017(99)00103-X.tr

Anous, M. R., and M. M. Mourad. 1993. Crossbreeding effects on reproductive traits of does and growth and carcass traits of kids. Small Rumin. Res. 12:141–149. doi:10.1016/0921-4488(93)90079-W

Baker, R. L., D. M. Mwamachi, J. O. Audho, E. O. Aduda, and W. Thorpe. 1998. Resistance of galla and small East African goats in the sub-humid tropics to gastrointestinal nematode infections and the peri-parturient rise in faecal egg counts. Vet. Parasitol. 79:53–64. doi:10.1016/S0304-4017(98)00151-4

Baker, R. L., D. M. Mwamachi, J. O. Audho, E. O. Aduda, and W. Thorpe. 1999. Genetic resistance to gastro-intestinal nematode parasites in Red; Maasai, Dorper and Red Maasai x Dorper ewes in the sub-humid tropics. Anim. Sci. 69:335–344. doi:10.1017/S1357729800050906

Barbato, G., R. Kremer, L. Roses, and L. Rista. 2011. Corriedale sheep production and F1 crosses with Texel Milchschaf and grazing conditions. Veterinaria. 47:9–13.

Batten, G. 2014. A new breeding pathway to improve meat goats. Livest. Res. Rural Dev. 26. http://www.lrrd.org/lrrd26/9/batt26155.html (Accessed 24 July 2016).

Bittante, G., L. Gallo, P. Carnier, M. Cassandro, R. Mantovani, and E. Pastore. 1996. Effects on fertility and litter traits under accelerated lambing scheme in crossbreeding between Finnsheep and an Alpine sheep breed. Small Rumin. Res. 23:43–50. doi:10.1016/0921-4488(95)00812-8

Boujenane, I., and G. E. Bradford. 1991. Genetic effects on ewe productivity of crossing d'man and sardi breeds of sheep. J. Anim. Sci. 69:525–530. doi:10.2527/1991.692525x

Boujenane, I., and J. Kansari. 2002. Lamb production and its components from purebred and crossbred mating types. Small Rumin. Res. 43:115–120. doi:10.1016/S0921-4488(01)00267-X

Boujenane, I., N. Roudies, A. Benmira, Z. EI Idrissi, and M. EI Aouni. 2003. On-station assessment of performance of the DS synthetic and parental sheep breeds, D'man and Sardi. Small Rumin. Res. 49:125–133. doi:10.1016/S0921-4488(03)00092-0

Browning, R. Jr., S. H. Kebe, and M. Byars. 2004. Preliminary assessment of Boer and Kiko does as maternal lines for kid performance under humid, subtropical conditions. South Afr. J. Anim. Sci. 34:1–3. https://hdl.handle.net/10520/EJC94415

Browning, R. Jr., M. L. Leite-Browning, and M. Byars, Jr. 2011. Reproductive and health trait among Boer, Kiko, and Spanish meat goat does under humid, subtropical pasture conditions of the southeastern United States. J. Anim. Sci. 89:648–660. doi:10.2527/jas.2010–2930

Browning, R., Jr, and M. L. Leite-Browning. 2011. Birth to weaning kid traits from a complete diallel of Boer, Kiko, and Spanish meat goat breeds semi-intensively managed on humid subtropical pasture. J. Anim. Sci. 89:2696–2707. doi:10.2527/jas.2011-3865

Casey, N. H., and W. A. Van Niekerk. 1988. The Boer Goat I. Origin, adaptability, performance testing, reproduction and milk production. Small Rumin. Res. 1:291–302. doi:10.1016/0921-4488(88)90056–9

Coles, G. C., F. Jackson, W. E. Pomroy, R. K. Prichard, G. von Samson-Himmelstjerna, A. Silvestre, M. A. Taylor, and J. Vercruysse. 2006. The detection of anthelmintic resistance in nematodes of veterinary importance. Vet. Parasitol. 136:167–185. doi:10.1016/j.vetpar.2005.11.019

Du, M., J. Tong, J. Zhao, K. R. Underwood, M. Zhu, S. P. Ford, and P. W. Nathanielsz. 2010. Fetal programming of skeletal muscle development in ruminant animals. J. Anim. Sci. 88(13 Suppl):E51–E60. doi:10.2527/jas.2009-2311

El-Tarabany, M. S., A. W. Zaglool, A. A. El-Tarabany, and A. Awad. 2017. Association analysis of polymorphism in kiss1 gene with reproductive traits in goats. Anim. Reprod. Sci. 180:92–99. doi:10.1016/j.anireprosci.2017.03.006

Erasmus, J. A. 2000. Adaptation to various environments and resistance to disease of the improved boer goat. Small Rumin. Res. 36:179–187.doi:10760454

Fogarty, N. M., G. E. Dickerson, and L. D. Young. 1984. Lamb production and its components in pure breeds and composite lines. II. Breed effects and heterosis. J. Anim. Sci. 58:301–311. doi.org/10.2527/jas1984.582301x

Fogarty, N. M., D. L. Hopkins, and R. V. D. Ven. 2000. Lamb production from diverse genotypes. 2. Carcass characteristics. Anim. Sci. 70:147–156. doi:10.1017/S1357729800051687

Gallivan, C., W. D. Hohenboken, and M. Vavra. 1987. Breed and heterosis effects on wool and lamb production of rotationally crossed ewes. J. Anim. Sci. 64:43–49. doi:10.2527/jas1987.64143x

Glimp, H. A. 1995. Meat goat production and marketing. J. Anim. Sci. 73:291–295. doi:10.2527/1995.731291x

Goolsby, M. K., M. L. Leite-Browning, and R. Browning, Jr. 2017. Evaluation of parasite resistance to commonly used commercial anthelmintics in meat goats on humid subtropical pasture. Small Rumin. Res. 146:37–40. doi:10.1016/j.smallrumres.2016.11.022

Goossens, B., S. Osaer, M. Ndao, J. Van Winghem, and S. Geerts. 1999. The susceptibility of djallonké and djallonké-sahelian crossbred sheep to *trypanosoma congolense* and helminth infection under different diet levels. Vet. Parasitol. 85:25–41.doi:10.1016/S0304-4017(99)00087-4

Greyling, J. P. C., V. M. Mmbengwa, L. M. J. Schwalbach, and T. Muller. 2004. Comparative milk production potential of indigenous and Boer goats under two feeding systems in South Africa. Small Rumin. Res. 55:97–105. doi:10.1016/j.smallrumres.2003.11.014

Hayes, E. G., R. V. Lourençon, P. Khanal, and R. Browning, Jr. 2016. Effect of creep feeding on meat goat kid traits at weaning. J. Anim. Sci. 95(Suppl. 1):16–17 (Abstr.). doi:10.2527/ssasas2017.034

Jiabi, P., D. Zegao, C. Taiyong, and G. Jiyun. 2001. Improvement effect of crossbreeding Boer goats and Sichuan Native goats. In: Proc. 2001 Int. Conf. Boer Goats. Guizhou, China, p. 183. 20–25 October 2001.

Kamarudin, N. A., M. A. Omar, and M. Murugaiyah. 2011. Relationship between body weight and linear body measurements in Boer goats. In: Proc. 6th Seminar Vet. Sci., Putra, Malaysia, p. 68–73. 11–14 January. http://psasir.upm.edu.my/27270/1/Proceedings%2014.pdf (Accessed 1 April 2016).

Kaplan, R. M., J. M. Burke, T. H. Terrill, J. E. Miller, W. R. Getz, S. Mobini, E. Valencia, M. J. Williams, L. H. Williamson, M. Larsen, et al. 2004. Validation of the FAMACHA eye color chart for detecting clinical anemia in sheep and goats on farms in the Southern United States. Vet. Parasitol. 123:105–120. doi:10.1016/j.vetpar.2004.06.005

Karua, S. K., and J. W. Banda. 1994. The performance of the small East African goats and their Saanen Crosses in Malawi. FAO. http://www.fao.org/Wairdocs/ILRI/x5472B/x5472b0i.htm (Accessed 29 September 2015)

Khanal, P., M. L. Browning, M. Byars, and R. Browning Jr. 2016. Effect of doeling traits at weaning on doe survival and reproductive rates through their first production year in the southeastern United States. J. Anim. Sci. 94(Suppl. 1):13 (Abstr.). doi:10.2527/ssasas2015-026

Kimmés, A. 1992. On Réunion Island: The goat, a traditional product. La Chevre. Inst. Anim. Sci., Paris, France. 189:46–49.

Long, T. E., D. L. Thomas, R. L. Fernando, J. M. Lewis, U. S. Garrigus, and D. F. Waldron. 1989. Estimation of individual and maternal heterosis, repeatability and heritability for ewe productivity and its components in Suffolk and Targhee sheep. J. Anim. Sci. 67:1208–1217. doi:10.2527/jas1989.6751208x

Maitra, A., R. Sharma, S. Ahlawat, M. S. Tantia, M. Roy, and V. Prakash. 2014. Association analysis of polymorphisms in caprine kiss1 gene with reproductive traits. Anim. Reprod. Sci. 151:71–77. doi:10.1016/j.anireprosci.2014.09.013

Malan, S. W. 2000. The improved Boer goat. Small Rumin. Res. 36:165–170. doi:10.1016/S0921-4488(99)00160-1

Menezes, L. M., W. H. Sousa, E. P. Cavalcanti-Filho, and L. T. Gama. 2016. Genetic parameters for reproduction and growth traits in Boer goats in Brazil. Small Rumin. Res. 136:247–256. doi.org/10.1016/j.smallrumres.2016.02.003

Meza-Herrera, C. A., J. M. Serradilla, M. E Muñoz-Mejías, F. Baena-Manzano, and A. Menendez-Buxadera. 2014. Effect of breed and some environmental factors on body weights till weaning and litter size in five goat breeds in Mexico. Small Rumin. Res. 121:215–219. doi:10.1016/j.smallrumres.2014.07.006

Montaldo, H., A. Juárez, J. M. Berruecos, and F. Sánchez. 1995. Performance of local goats and their backcrosses with several breeds in Mexico. Small Rumin. Res. 16:97–105. doi:10.1016/0921-4488(95)00624-T

Nasrat, M. M., J. C. Segura Correa, and J. G. Magaña Monforte. 2016. Breed genotype effect on ewe traits during the pre-weaning period in hair sheep under the tropical Mexican conditions. Small Rumin. Res. 137:157–161. doi:10.1016/j.smallrumres.2016.03.026

Nguluma, A., M. L. Leite Browning and R. Browning. 2013. Comparison of Boer-cross and foundation breeds for meat goat fitness in the humid subtropics. Livest. Res. Rural Dev. Vol. 25, Article 38. http://www.lrrd.org/lrrd25/3/ngul25038.htm (Accessed 1 October 2014).

Nitter, G. 1978. Breed utilization for meat production in sheep. Anim. Breed. Abstr. 46:131–143.

Pillai, S. M., A. K. Jones, M. L. Hoffman, K. K. McFadden, S. A. Reed, S. A. Zinn, and K. E. Govoni. 2017. Fetal and organ development at gestational days 45, 90, 135 and at birth of lambs exposed to under-or over-nutrition during gestation. Translational Anim. Sci. 1:16–25. doi:10.2527/tas2016.0002

Rhind, S. M., M. T. Rae, and A. N. Brooks. 2001. Effects of nutrition and environmental factors on the fetal programming of the reproductive axis. Reproduction. 122:205–214. doi: 10.1530/rep.0.1220205

Rhone, J. A., D. F. Waldron, and A. D. Herring. 2013. Performance of boer-spanish and spanish goats in texas I: body weights, fertility, prolificacy, and number of kids weaned. J. Anim. Sci. 91:4679–4683. doi:10.2527/jas.2013-6227

Rhone, J. A., D. F. Waldron, and A. D. Herring. 2016. Performance of Boer-Spanish and Spanish does in Texas: kid production and doe stayability. Sheep Goat Res. J. 31:54–59.

Riley, D. G., C. C. Chase Jr., S. W. Coleman, and T. A. Olson. 2007. Evaluation of birth and weaning traits of Romosinuano calves as purebreds and crosses with Brahman and Angus. J. Anim. Sci. 85:289–298. https://doi.org/17235015

Shrestha, J. N. B. and M. H. Fahmy. 2007. Breeding goats for meat production: 2. Crossbreeding and formation of composite population. Small Rumin. Res. 67:93–112. doi:10.1016/j.smallrumres.2005.10.018

Tsukahara, Y., Y. Choumei, K. Oishi, H. Kumagai, A. K. Kahi, J. M. Panandam, T. K. Mukherjee, and H. Hirooka. 2008. Effect of parental genotypes and paternal heterosis on litter traits in crossbred goats. J. Anim. Breed. Genet. 125:84–88. doi:10.1111/j.1439-0388.2007.00692.x

USDA-NASS. 2018. Sheep and Goats. National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA). 19 pp. ISSN: 1949–1611. http://usda.mannlib.cornell.edu/usda/current/SheeGoat/SheeGoat-01-31-2018.pdf (Accessed 30 September 2018).

Wang, L., A. Nguluma, M. L. Leite-Browning, and R. Browning. 2017. Differences among four meat goat breeds for doe fitness indicator traits in the Southeastern United States. J. Anim. Sci. 95:1481–1488. doi:10.2527/jas.2016.1283

Wilson, R. T., and D. Light. 1986. Livestock production in central Mali: economic characters and productivity indices for traditionally managed goats and sheep. J. Anim. Sci. 62:567–575. doi:10.2527/jas1986.623567x

Wilson, R. T., and T. Murayi. 1988. Productivity of the small East African goat and its crosses with the anglo-nubian and the alpine in rwanda. Trop. Anim. Health Prod. 20:219–228. doi:10.1007/BF02239986

Yazwinski, T. A., L. Goode, D. J. Moncol, G. W. Morgan, and A. C. Linnerud. 1979. Parasite resistance in straightbred and crossbred barbados blackbelly sheep. J. Anim. Sci. 49:919–926. doi:10.2527/jas1979.494919x

Yonghong, H., C. Qinkang, H. Genghua, and Y. Zhangping. 2001. Effect of Boer goat crossbreeding with Haimen goats and Huai goats in Jiangsu province. In: Proc. 2001 Int. Conf. Boer Goats, Guizhou, China. p. 192–197. Oct. 20–25, 2001.

Zhang, C. Y., S. L. Chen, X. Li, D. Q. Xu, Y. Zhang, and L. G. Yang. 2009. Genetic and phenotypic parameter estimates for reproduction traits in the Boer dam. Livestock Sci. 125:60–65. doi:10.1016/j.livsci.2009.03.002