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The Effects of Maternal Diet During Gestation on Offspring Frame Size and Growth in Sheep

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Abstract

Poor maternal nutrition negatively affects the health of the offspring including changes in growth and development. Body morphometrics, including body weight, height, length, girth, and body condition score, are commonly used to monitor the health and growth of livestock. However, correlations of ewe and lamb body morphometrics in the presence of poor maternal nutrition have not been well studied. Therefore, we hypothesized that over- and under- feeding ewes during gestation would cause negative effects on the normal body frame measurements of the lamb. To test this, 46 multiparous individually housed ewes, ranging from 2 to 7 years old, were randomly assigned one of three diets based on the National Research Council requirements for total digestible nutrients (TDN) for pregnant ewes: control, CON (100% of TDN, n = 13), restricted , RES (60% of TDN, n = 17), or over-fed, OVER (140% of TDN, n = 16). Ewe body measurements were taken during gestation, day 55.03± 6.48, and include crown-rump length (CRL), height, girth, and length. Offspring (n = 91, CON = 26, RES = 34, OVER = 31) measurements were taken on day 0, 7, and 120 of age and include weight, CRL, and girth. Data were analyzed using the CORR procedure in SAS comparing the ewe body measurements with the respective lamb body measurements in each treatment. There were no significant differences in ewe CRL, height, girth, or length between treatments ($P > 0.053$). There were no correlations of lamb and ewe variables in RES ($r < 0.39$) and OVER ($r < 0.60$). These results suggest that the ability to predict the size of the offspring is weakened when maternal over- and restricted- diets are present. This may be due to increased variation in the size of the offspring.

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Introduction

Global warming in combination with an increasing global population and rising average household income are all factors that need to be met with a heightened but sustainable food supply. Meat is an important source of protein and is an essential source of nutrients, including iron, zinc, and B12, especially for people of lower income (Godfray et al., 2018). The economic impact of livestock production affects products in food, retail, health care, and household items. In 2014, beef production contributed $165 billion to the US economy and in 2020 beef exports reached $7.4 billion. (USDA, 2021). Livestock also makes up 40% of agriculture output by both price and meat production (Godfray et al., 2018). The CH4, CO2, and N2O emission from livestock and livestock processing, around 15% of all anthropogenic emissions, has been a large source of greenhouse gases, which will be reduced if livestock are more efficient (Godfray et al., 2018). However, environmental conditions also impact livestock production. For example, droughts have reduced forage production which causes sheep and cattle, which primarily depend on forage, to undergo periodic nutrient deficiency (Du et al., 2015). Periodic nutrient deficiency is problematic because they can be nutrient deficient during pregnancy, causing negative effects on the offspring's growth and development, even into later life (Du et al., 2015).

Fetal Programming

In both humans and animals, the "fetal origins" hypothesis proposes that changes in the fetal nutrients and hormone concentrations create developmental adaptations, both physiologically and metabolically. These changes cause endocrine and metabolic diseases as an adult (Godfrey and Barker 2001). Research from Godfrey and Barker (2001) was seminal work in the field and challenged a previous notion that the fetus is little affected by changes in maternal nutrition. Fetal programming occurs during critical periods of fetal development and ultimately alters the course of development, resulting in long-lasting effects (Du et al., 2013). Available studies show that maternal nutrition affects the development of fetal skeletal muscle and adipose tissue, which exert long-term effects on the growth performance and meat quality of offspring (Du et al., 2015). For example, the amount of intramuscular fat is determined by the number and size of intramuscular adipocytes and fetal programming has a major effect on the number of adipocytes in offspring (Du et al., 2015). Intramuscular fat is sought after in the meat industry, called marbling. Marbling is an important quality because higher grade meats receive higher prices (Lonergan et al., 2019). However, with proper maternal nutrient supplementation, studies found improved fetal skeletal muscle development and adipogenesis in fetal and pre-weaning skeletal muscle, which enhances marbling in the offspring (Du et al., 2015). Other examples of the effects of maternal nutrition include altered offspring hepatic glucose production, cholesterol metabolism, insulin secretion, and renal development (Godfrey and Barker 2001). Fetal growth restriction has been implicated as the cause of harmful postnatal offspring performance defects or traits, including lower birth weights, poor offspring, and poor growth body composition. A major cause is compromised maternal nutrition (Peine et al., 2018).

Effects of Ewe Maternal Nutrition on Offspring

Maternal nutrition has been linked to overall health of their young. In the Western United States, pregnant grazing ewes often receive less than 50% of NRC recommendations, resulting in loss of body weight during pregnancy and reduced lactational performance (Peine et al., 2018). Overall, depleted or excessive maternal nutrition reserves can alter nutrient availability to the developing fetus and compromise fetal growth which thereby alters adult life (Wu et al., 2006). Previous studies have shown that under-nutrition in ewes caused both maternal and fetal nutrient status to be reduced as well as reduced placental growth factors (McMullen et. al., 2004). These negative effects can reduce the survival of the offspring and cause damage to the health of the lamb postnatally and as an adult (Ford and Long, 2011). Sheep fetal programming research has shown that undernutrition in the second and third trimester of gestation causes a decrease in lamb weight and requires a minimum of 120 days after for the lambs to achieve a healthy, normal weight (Sartori et al., 2020) but the weight reduction does not affect lamb body measurements. During the last third of gestation, there was no fetal weight reduction in over-fed multiparous ewes compared with control-fed ewes but fetal weight was reduced in over-fed primiparous ewes compared with control-fed ewes (Sartori et al., 2020). Sartori et al. (2020) concluded that maternal nutrition of ewes during pregnancy has effects on fetal and postnatal weight, but not size. RES-fed treatment lambs become programmed to live on minimal nutrients whereas OVER-fed treatment lambs become programmed to live on excess nutrients which can lead to increased fat accumulation in the adult offspring (Pillai et al., 2017). The fetal nutrient environment is a determinant of metabolic disease in later life (Ford and Long, 2011). In offspring of under-fed pregnant ewes, glucose tolerance was reduced. The reduction in glucose tolerance was no longer detectable by adulthood but may have possibilities for weight gain and obesity (Costello et al., 2004).

Body Weight and Body Condition Scores

There are many factors used to determine animal health and market value; the most straightforward is body weight. Productivity of each ewe is measured by her own body weight and the growth rate and the body weight of her lamb (Gebrelul, 1984). In the US sheep market, there is a trend to increase body weight to increase price at sale (Gebrelul, 1984). Body weight of each ewe is composed of the skeletal size and fatness. However, body weight alone does not account for the condition of the animal (Gebrelul, 1984). Body condition scoring (BCS) is a widely used, but also subjective, measure of body condition which can distinguish differences in nutritional needs to ensure effectiveness of diets and can be used to compare individuals in a flock (Semakula et al., 2020). A common BCS system for sheep is a scale of 0 to 5 (while some can be 1 to 9), including half and quarter values, and uses visual cues or palpation of the lumbar vertebrae and hip bones to measure the level of body fatness. BCS is different from body weight in that no measuring scale is needed, it can be done rapidly, and it does not account for fleece weight or gut-fill (Semakula et al., 2020). A BCS of 0 is an extremely poor score and is indicative of no fat and little muscle, prone to disease and high risk of death. Each rib is easily detectable, the spine is sharp and prominent, and there is no subcutaneous fat cover (Gebrelul, 1984). A BCS of 5 is equally as also bad with too much fat over the backbone and ribs and is typically too large for slaughter. There is a depression in the subcutaneous fat where the spinous processes cannot be felt and there are large fat deposits over the rump end and tail (Gebrelul, 1984). A good BCS for a healthy adult sheep is 3 with a range of 2.5 to 3.5 for pregnant ewes (Semakula et al., 2020). Since BCS is a subjective measuring method typically more than one person scores the sheep and the average is taken. This method is also cost effective and helps producers monitor trends. BCS helps with routine weighing and maximizing overall livestock productivity because BCS is typically positively and linearly associated with liveweight. But despite BCS and liveweight being linearly correlated, Semakula et al. (2020) found the relationship to be weak so early life live weights alone are not reliable to predict future BCS. This result means that early life body weights cannot predict the future BCS. However, BCS and body weight cannot always identify acute problems because changes in body weight and BCS take time to occur. For example, when pregnant ewes were fed control, restricted, or overfed diets, changes in ewe BW was not documented until ewes were on diet for at least 15 days, when restricted ewes weighed less than overfed ewes and overfed ewes weighed more than control ewes (Pillai et al., 2017). In the same study, no differences in BCS were identified until day 135 of gestation when over-fed ewes had greater BCS than control-fed ewes, and the restricted-fed ewes had lower BCS than the control-fed ewes. At parturition, the control- and over-fed ewes had similar BCS.

Correlations Between Maternal and Fetal Body Size

Appropriate body size can help livestock adapt to climates, utilize feed resources, and improve market price. While larger animals are more energetically efficient because they have a smaller surface area per unit of volume and overall smaller heat production, smaller animals can convert nutrients into protein faster and reproduce earlier (Gebrelul, 1984). The liveweight of the ewe is highly heritable and is the primary criteria for replacement ewe selection (Gebrelul, 1984). Body weight increases and eventually plateaus as the sheep mature (Gebrelul, 1984). Body weight is an effective predictor of ovulation rate, so bigger ewes have more ovulations than smaller ewes (Gebrelul, 1984). Ewe body weight and ewe body size were positively related to prolificacy, weaning rate and total weight of lamb weaned per ewe lambing and negatively related to the total weight of lamb weaned per unit ewe weight and size (Gebrelul, 1984). The total weight of lamb weaned per ewe lambing (both weaning rate and weaning weight of lamb) was positively related to ewe weight and size but the relationship was stronger in the lighter ewes (Gebrelul, 1984). Using different crosses of sheep breeds, Gebrelul (1984) study found a positive significant ($P < 0.05$) correlation that revealed the heavier the ewe the higher the lamb body weight was at birth (Gebrelul, 1984).

Effect of Genetic Factors on Lamb Body Weight

Genetics play a large part in increasing livestock efficiency. Expression of specific genes is associated with enhanced animal growth, health, and utilization of nutrients. These changes have the potential to increase production while decreasing the livestock carbon footprint. An important way to increase production through genetics is through increasing reproductive efficiency. In sheep, this relates to increasing the number of lambs born per ewe and the frequency of lambing (Gebrelul, 1984). Romanov sheep are a super-prolific breed and have been introduced to greatly improve ewe productivity in the US over the past 30 years (Murphy et al., 2020). Prolificacy is a composite trait and incorporates factors of ovulation and fertilization rate, uterine environment, and fetal survival rate (Murphy et al., 2020). It is unclear how much genetic and nongenetic variations occur among rams (Murphy et al., 2020). Murphy et al. (2020) determined genetic and nongenetic effects for ewe reproductive performance and lamb body weight of Romanov sheep. They found that the Romanov closed flock had moderate maternal heritability for body weight at birth but low heritability for weaning body weight and overall low direct heritabilities for all body weight traits (Murphy et al., 2020). They concluded that even though the heritability of ewe reproductive performance and lamb body weight was low, the selection strategies are still compelling enough to maintain the genetic diversity (Murphy et al., 2020). Cross breeding sheep may increase fertility, prolificacy, number of lambs, and total weight of lambs, although varying factors of ewe age, management systems, and longevity of the ewes may impact success. Gebrelul et al. (1984) used Targhee ewes crossed with three different rams (Targhee, Finnsheep, and Suffolk) breeds because the Targhee breed has been found to have good reproductive performance in respect to the total weight of lamb weaned when compared to six other common US breeds (Gebrelul, 1984). The relationship between ewe body weight and body weight of lamb born per ewe was negative in Finnsheep x Targhee crosses, while Targhee x Targhee and Suffolk x Targhee crosses resulted in positive relationships which suggest that the heavier the ewe the less she will produce relative to her body weight (Gebrelul, 1984).

Other Frame Size Measurements and Carcass Yield

Another indicator of livestock health and growth is frame size. Frame size is defined as the skeletal size in relation to age (Tatum et al., 1998). In cattle, frame size, finishing weight, and carcass quality grade are used to classify animals for market (Tatum et al., 1998). Tatum et al. (1998) tested five different finishing diets on small, medium, and large framed feeder lambs. Daily gains for the large lambs were greater than daily gains for the small lambs in all the dietary treatment groups, except the diet of 80% concentrate with 14.5% crude protein (Tatum et al., 1998). Tatum et al. (1998) found that feeder lamb frame size was indicative of differences in growth rate during finished and claimed a grading system could be constructed based on feeder lamb frame size to predict the end point carcass grade. Specific measurements such as girth, length, height, and crown rump length (CRL) are indicators of growth and health in sheep and are used in combination to determine standards. Mellor and Matheson (1979) (cite) found that adequately nourished ewes during the last third of gestation, a fetal weight average increase of 15g there was a 1mm increase in CRL (). A 2020 study by Sabbioni et al. (2020), found using the goodness of fit (R^2 and RMSE in SAS) that body weight of Cornigliese sheep can be predicted with good precision and accuracy using linear body measurements, including height at withers, chest circumferences, and length. The effects of maternal nutrition on fetal size seems to be time dependent and is observed at birth whereas differences in fetal organ mass were observed between day 45 and 90 of gestation (Pillai et al., 2017). For example, CRL was shorter in offspring born to restricted-fed ewes than lambs from control- and over-fed ewes, regardless of the stage of gestation (Pillai et al., 2017).

Age of Ewe on Offspring Size

Age or maturity of the ewe is another factor used to impact the health of the offspring. Lambs born to adolescent ewes have lower lamb birth weights and shorter mean crown rump length then when compared with mature ewes. Adolescent ewes develop smaller placentas with fewer cotyledons which give rise to lambs of lighter birth weight. Under the same diet, however, mature ewes did not have placental or lamb weight changes (Wallace et al, 2005). During a high nutrient study, adolescent ewes were more sensitive after mating than mature ewes but increasing weight loss for the adolescent ewes after mating, increases their conception rate (Annett and Carson, 2006). The ewes were fed high nutrients during the first month of pregnancy and found that lamb birth weights of both the adolescent and mature ewes were not affected which demonstrated that the growth potential and the placental capacity for nutrient transfer were not impacted by increased nutrients during the first month of pregnancy (Annett and Carson, 2006).

Fetal Organ Growth and Fat Accumulation

Both maternal under- and over-feeding can cause offspring to exhibit reductions in muscle development, increase adiposity, and altered body size and composition (Hoffman et al., 2014). Both body weight and crown-rump length between CON- and RES-fed treatment lambs were not different pre- and post-weaning (Hoffman et al., 2014). During the postweaning period, lambs from over-fed ewes have a greater BCS score than control-fed treatment lambs and restricted-fed treatment lambs (Hoffman et al., 2014). Lambs from over- and under- fed ewes may accumulate less protein/muscle tissue and therefore have reduced carcass quality (Hoffman et al., 2014). Another study, Pillai et al., 2017 found no differences between OVER- and RES-maternal diets and the respective fetal body weight. However, at birth, the RES-fed treatment lambs weighed 18.4% less than CON-fed treatment lambs, and 13.1% less than OVER-fed treatment lambs (Pillai et al., 2017). At day 135, OVER lambs had more perirenal fat but at birth the RES lambs had more perirenal fat than CON and OVER lambs (Pillai et al., 2017). Overall, Pillai study (2017) determined that both maternal restriction- and over-feeding during gestation differentially alter organogenesis of the liver and kidneys during early gestation but body size and composition during late gestation through parturition (Pillai et al., 2017).

Conclusion

The need for more efficient animals has many reasons: increasing global population, climate change, human and animal health, and the economy. An initial step in increasing livestock efficiency is looking at the effects of maternal nutrition on the growth of the offspring. This current study allows for direct comparison of the lamb body measurements to their respective dam body measurements and age so that we could compare the effects of each of the three diets in the same environment. In conclusion, prior evidence shows that poor maternal nutrition differentially alters offspring body size depending on the stage of gestation (Pillai et al., 2017). We hypothesized that over- and under- feeding ewes during gestation would cause negative effects on the normal body frame measurements of the lamb. The specific objective for this experiment was to measure the changes in body frame measurements and compare the OVER and RES fed offspring and see if the predictability of offspring growth would be retained.

Materials and Methods

Animals and Sample Collection

All animal procedures were reviewed and approved by the University of Connecticut's Institutional Animal Care and Use Committee protocol number: A19-018. This project used multiparous Dorset ewes (n=46) ranging from 2 to 7 years old (3.22 $\pm$ 0.25). Each ewe was bred to one of three rams and the breeding date was recorded as the day the ewes were marked by the ram. Around day 20 of gestation, the ewes were moved to individual pens and confirmed pregnant with twins via ultrasonography. Ewes were randomly assigned one of three diets based on the National Research Council requirements for total digestible nutrients (TDN) for pregnant ewes: control (100% of TDN, n=13), restricted (60% of TDN, n=17), or over-fed (140% of TDN, n=16). Ewes, and their respective birthed lambs, on the control-, restricted, and over-fed diets will be referred to as CON, RES, and OVER, respectively, hereafter. Ewes were transitioned to a complete pelleted feed (Pleasantview Farms, Putnam, CT) over a seven-day transition period, such that their experimental diet started at day 30 of gestation. Ewe bodyweight was used to adjusted on a weekly basis. A total of 91 lambs were born, consisting of 51 ram lambs (n = 15 CON, n = 21 RES, n = 15 OVER) and 40 ewe lambs (n = 11 CON, n = 13 RES, n = 16 OVER). After parturition, ewes were transitioned to second cut hay and pelleted feed (Blue Seal, Muscatine, IA) and lambs were provided ad lib access to creep feed (Blue Seal). Lambs were weaned 60 days of age and maintained on second cutting hay and creep feed.

Measurements

Ewes body morphology measurements (cm) were taken once in early gestation using a tailor's tape to measure crown-rump length (ECRL), height (EHeight), girth (EGirth), and length (ELength). Crown-rump length begins at the base of the neck to the tail head. Height was measured with the ewe on level ground, against a wall, measuring the right front leg beginning at the shoulder to the ground. Girth was measured behind both front legs, around the spine, pulling the tape measure tight in order to discount the wool thickness. Length was measured on the parallel line from the front of the shoulder blade to the back of the buttocks. Lamb body weight (LBW), crown-rump length (LCRL), and girth (LGirth) measurements were taken at 0, 7, and 120 days of age. Measurements for 16 lambs were missing from day 7 (n = 3 CON, n=7 OVER, and n= 6 RES) due to reasons unrelated to the study.

Statistical Analysis

Pearson correlation coefficients for ewe and lamb variables at day 0, 7, and 120 days of age were analyzed within treatment groups and within the entire study population using the CORE procedure in SAS (SAS Institute, Inc., Cary, NC) comparing ewe age, ECRL, EHeight, EGirth, and ELength with LBW, LCRL, and LGirth. Data are presented as means $\pm$SEM. *P*-values were considered significant at $P \leq 0.05$ and correlations were considered strong at r $\geq$0.7.

<u>Results</u>

Correlations of ewe variables in each treatment

For all treatment ewes, there were weak P values between girth (P=0.056) and length (P=0.053; Table 1). There were no significant correlations between CRL, girth, or length ($r \geq 0.7$ and $P \leq 0.05$). The over-fed dams had the highest CRL (116 ± 2.18), height (83.7 ± 1.42), girth (112 ± 1.86), and length (92.2± 1.39) average. The restricted-fed dams were the oldest (3.28 ± 0.447).

Correlations of lamb and ewe variables in control-fed dams

Within control-fed animals, there were significant correlations between ewe age and lamb body weight ($r = 0.715$, $P < 0.0001$) and lamb girth ($r = 0.729$, $P < 0.0001$) at day 0 (Table 2). There were significant correlations of lamb girth with ewe height ($r = 0.708$, $P = 0.0$) and ewe girth ($r = 0.719$, $P = 0.0$) on day 7. There were no significant correlations of lamb variables with ewe CRL or ewe length.

Correlations of lamb and ewe variables in restricted-fed dams

In restricted-fed ewes and their offspring, there were no significant correlations ($r \geq 0.7$ and $P \leq 0.05$) between ewe age, CRL, height, girth, or length with any lamb variables (Table 3). All significant correlations were weak associations ($r < 0.391$).

Correlations of lamb and ewe variables in over-fed dams

In over-fed dams and their offspring, there were no significant correlations ($r \geq 0.7$ and $P \leq 0.05$) between ewe age, ewe CRL, ewe height, ewe girth, or ewe length with any lamb variables (Table 4). All significant correlations were weak associations ($r < 0.602$).

Correlations of lamb and ewe variables in control-, restricted-, and over-fed dams

For all treatment groups together, there were no significant correlations ($r \geq 0.7$ and $P \leq 0.05$) for ewe age, ewe CRL, ewe height, ewe girth, or ewe length with any lamb variables (Table 5). All significant correlations were weak associations ($r < 0.376$).

Table 1. Correlations between all treatment dams[1]

	Diet[2]			
	CON	RES	OVER	P-value
Ewe Age	3.15 ± 0.511	3.28 ± 0.447	2.81 ± 0.460	*0.758*
Ewe CRL[3]	111 ± 2.42	112 ± 2.12	116 ± 2.18	*0.397*
Ewe Height	83.6 ± 1.58	82.9 ± 1.38	83.7 ± 1.42	*0.914*
Ewe Girth	109 ± 2.07^{ab}	107 ± 1.81^{a}	112 ± 1.86^{b}	*0.056*
Ewe Length	88.9 ± 1.55^{ab}	87.3 ± 1.35^{a}	92.2± 1.39^{b}	*0.053*

[1] n = 46 dams, n= 13 CON, n= 17 RES, n= 16 OVER

[2] RES: 60% of NRC requirements; CON: 100% of NRC requirements; OVER: 140% of NRC requirements

[3]CRL = crown rump length

^{ab} Means with different superscripts are different, $P < 0.05$

Table 2. Correlations between control-fed dams[1] and offspring on days 0, 7 and 120 of age[2]

	Ewe Age	Ewe CRL[3]	Ewe Height	Ewe Girth	Ewe Length
Day 0					
Lamb BW[4]	0.715	0.273	0.506	0.506	0.579
	<0.0001	*0.178*	*0.008*	*0.008*	*0.002*
Lamb CRL	0.637	0.500	0.456	0.359	0.621
	0.001	*0.009*	*0.019*	*0.071*	*0.001*
Lamb Girth	0.729	0.074	0.607	0.515	0.326
	<0.0001	*0.718*	*0.001*	*0.007*	*0.104*
Day 7					
Lamb BW	0.551	0.265	0.620	0.605	0.592
	0.004	*0.110*	*0.001*	*0.001*	*0.002*
Lamb CRL	-0.050	0.419	0.087	0.076	0.322
	0.826	*0.052*	*0.700*	*0.737*	*0.144*
Lamb Girth	0.569	0.213	0.708	0.719	0.528
	0.006	*0.341*	*0.000*	*0.000*	*0.012*
Day 120					
Lamb BW	0.294	0.455	0.128	0.235	0.370
	0.174	*0.029*	*0.561*	*0.130*	*0.083*
Lamb CRL	0.277	0.479	0.057	0.202	0.389
	0.200	*0.021*	*0.796*	*0.356*	*0.066*
Lamb Girth	0.412	0.420	0.277	0.518	0.662
	0.051	*0.046*	*0.201*	*0.011*	*0.001*

[1] n = 13 dams, n = 26 offspring; 15 rams and 11 ewes
[2] Correlation coefficients and *P-values* presented for each comparison
[3] CRL = crown rump length
[4] BW = body weight

Table 3. Correlations between restricted-fed dams[1] and offspring on days 0, 7 and 120 of age[2]

	Ewe Age	Ewe CRL[4]	Ewe Height	Ewe Girth	Ewe Length
Day 0					
Lamb BW[5]	0.199	-0.394	0.238	0.353	-0.065
	0.258	*0.021*	*0.174*	*0.040*	*0.713*
Lamb CRL	0.356	-0.019	-0.017	-0.009	0.172
	0.258	*0.916*	*0.927*	*0.963*	*0.344*
Lamb Girth	-0.077	-0.060	0.031	-0.161	-0.064
	0.675	*0.745*	*0.865*	*0.378*	*0.728*
Day 7					
Lamb BW	-0.057	-0.541	0.170	0.329	-0.114
	0.748	*0.001*	*0.335*	*0.058*	*0.521*
Lamb CRL	-0.115	-0.059	0.023	0.391	0.036
	0.545	*0.755*	*0.904*	*0.032*	*0.850*
Lamb Girth	-0.028	-0.505	0.040	0.042	-0.215
	0.884	*0.005*	*0.836*	*0.023*	*0.262*
Day 120					
Lamb BW	-0.043	-0.352	0.217	-0.096	-0.022
	0.811	*0.041*	*0.218*	*0.588*	*0.901*
Lamb CRL	-0.007	0.244	-0.231	-0.318	0.046
	0.970	*0.164*	*0.188*	*0.067*	*0.796*
Lamb Girth	0.053	-0.311	0.222	-0.123	-0.406
	0.765	*0.073*	*0.206*	*0.487*	*0.017*

[1] n = 17 dams, n = 34 offspring; 21 rams and 13 ewes
[2] Correlation coefficients and *P-values* presented for each comparison
[3] CRL = crown rump length
[4] BW = body weight

Table 4. Correlations between over-fed dams[1] and offspring on days 0, 7 and 120 of age[2]

	Ewe Age	Ewe CRL[2]	Ewe Height	Ewe Girth	Ewe Length
Day 0					
Lamb BW[3]	0.292	-0.039	0.481	0.024	0.177
	0.110	*0.830*	*0.006*	*0.900*	*0.342*
Lamb CRL	0.417	-0.138	0.527	0.062	0.377
	0.022	*0.468*	*0.003*	*0.744*	*0.040*
Lamb Girth	0.290	-0.047	0.460	0.043	0.193
	-0.045	*0.807*	*0.011*	*0.823*	*0.308*
Day 7					
Lamb BW	0.330	-0.034	0.241	0.171	0.044
	0.075	*0.858*	*0.199*	*0.367*	*0.816*
Lamb CRL	0.061	-0.180	0.249	-0.079	0.198
	0.774	*0.390*	*0.230*	*0.708*	*0.344*
Lamb Girth	0.310	-0.160	0.352	0.186	0.200
	0.124	*0.435*	*0.078*	*0.364*	*0.327*
Day 120					
Lamb BW	0.470	0.195	0.116	-0.117	0.059
	0.008	*0.294*	*0.534*	*0.532*	*0.752*
Lamb CRL	0.602	0.355	0.134	0.163	-0.247
	0.000	*0.054*	*0.479*	*0.389*	*0.189*
Lamb Girth	0.344	0.043	0.213	-0.071	0.191
	0.063	*0.821*	*0.259*	*0.708*	*0.311*

[1] n = 16 dams, n = 31 offspring; 15 rams and 16 ewes
[2] Correlation coefficients and *P-values* presented for each comparison
[3] CRL = crown rump length
[4] BW = body weight

Table 5. Correlations between all treatment-fed dams[1] and offspring on days 0, 7 and 120 of age[2]

	Ewe Age	Ewe CRL[3]	Ewe Height	Ewe Girth	Ewe Length
Day 0					
Lamb BW[4]	0.333	0.040	0.421	0.287	0.321
	0.001	*0.705*	*<0.0001*	*0.006*	*0.020*
Lamb CRL	0.376	0.096	0.276	0.123	0.340
	0.000	*0.373*	*0.009*	*0.256*	*0.001*
Lamb Girth	0.005	-0.035	0.051	-0.112	-0.049
	0.965	*0.748*	*0.636*	*0.300*	*0.653*
Day 7					
Lamb BW	-0.112	-0.024	0.322	0.319	0.206
	0.331	*0.824*	*0.002*	*0.002*	*0.053*
Lamb CRL	-0.112	0.035	0.160	0.157	0.263
	0.331	*0.764*	*0.166*	*0.171*	*0.021*
Lamb Girth	0.166	-0.098	0.347	0.325	0.168
	0.149	*0.397*	*0.002*	*0.004*	*0.144*
Day 120					
Lamb BW	0.199	0.117	0.137	0.025	0.114
	0.064	*0.278*	*0.202*	*0.815*	*0.292*
Lamb CRL	0.244	0.289	0.001	-0.009	0.038
	0.023	*0.007*	*0.991*	*0.932*	*0.725*
Lamb Girth	0.214	0.051	0.224	0.052	0.133
	0.047	*0.636*	*0.037*	*0.633*	*0.220*

[1] n = 46 dams, n = 91 51 rams and 40 ewes
[2] Correlation coefficients and *P-values* presented for each comparison
[3] CRL = crown rump length
[4] BW = body weight

Discussion

Livestock research has demonstrated that maternal body size impacts lamb size at birth and subsequent growth. Maternal nutrition studies have demonstrated that under- and over-feeding ewes during gestation can negatively impact the offspring fetal growth and development. In this study, we found that all ewes before treatment did not differ significantly in size or measurements. And while the CON-treatment group had significant correlations, the correlations were lost for the RES- and OVER-fed treatment groups.

When comparing all the ewe treatment groups, girth and length had weak *P*-values ($P < 0.056$). These specific relationships have never been discussed before. Hoffman et al. (2016), studied ewe ADG in the treatment group but not comparing the ewes before trial. This comparison is useful to see where all the ewes began, in terms of size, and the lack of correlations prove that the ewes all started with similar body measurements. This is beneficial to know so that ewe body sizes were not impacting certain treatment groups more than others.

At birth, CON ewe age was positively correlated with lamb BW and lamb girth. As the ewe ages, lamb body weight and lamb girth increased. At 7 days of age, ewe height and girth were positively correlated with lamb girth. However, the RES and OVER groups had no significant correlations between ewe and lamb variables at any time point measured. The lack of correlations in the RES and OVER treatment groups in the first 120 days indicates that over- and under-feeding ewes during all of gestation means the ability to predict the size of the offspring is lost. The loss of correlations from the CON-treatment lambs means the RES- and OVER-fed diets increased the variation in the size of the offspring. This variation directly relates to how the offspring develop. The results of this study do support our hypothesis because the diets created negative effects on the normal body frame measurements of the lamb. When the RES- and

OVER-fed diets were imposed on the ewes, there were changes in the amount of impact that the normal maternal environment has on the offspring. This loss of correlation means the effects are not impacting the lambs equally.

This study is useful because it allows us to predict the impact of the offspring development in an individual manner. The diets are disrupting the correlations from the normal, healthy diet. These results support the studies from Hoffman et al., 2016, which compared the different treatment lambs to each other, found that there were no differences in BW or average daily gain between the CON and RES lambs. And there were also no differences in CRL between CON and RES lambs at any point (Hoffman et al., 2016). Pillai et al. (2017) found that CRL was shorter for RES lambs than CON or OVER. Our study is different because we are taking a group comparing ewes and lambs and seeing if ewe size impacts lamb size, which it does in the control. But the impact is lost when introducing the different CON and RES diets.

The results of this study were unexpected and may indicate the diets were not severe enough to cause changes in growth in offspring development. The missing day 7 lamb body measurements are not enough to account for the lack of significant correlations. However, other studies have found that fetal organ growth was altered which altered organ function (Reed et al., 2007). Pillai et al. (2017) found that heart girth was smaller at birth in the RES offspring than the CON or OVER. Even though this study found no correlations with RES and OVER body measurements, that does not mean that internally the offspring are similar to each other or are healthy.

Further research is needed to fully understand the impact of altering maternal diet during gestation. In sheep, growth catch up occurs within the first 30 to 45 days so there would be no benefit to extend the measurement days. However, there could be a benefit in comparing the sire size to the lambs to see how much, if any, the paternal diet impacts offspring growth. There is already evidence that poor maternal nutrition is correlated with oxidative stress, reduced muscle and organ development, and altered glucose tolerance (Hoffman et al. 2016 and Pillai et al. 2017). More research could include BCS scoring in order to determine if these results are detectable in a production setting.

Conclusion

Overall, the need for more productive livestock is necessary for the increase in population and the threat of global warming. However, breeding larger animals with large animals is not the best solution as many factors influence growth in utero. Through studies of varied maternal nutrition, the ability to predict the size of the offspring is lost as variation increases.

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