Libyan Open University Journal of Applied Sciences (LOUJAS)
Volume 2 - Issue 1 - 2026 - Pages 530-542

Pregnancy Diagnosis and Fetal Age Estimation Using Ultrasonography in Goats

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تشخيص الحمل وتقدير عمر الجنين باستخدام التصوير بالموجات فوق الصوتية في الماعز

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Received: 22-03-2026; Accepted: 22-05-2026; Published: 04-06-2026

Abstract

Managing reproduction in dairy goat herds depends heavily on timely pregnancy diagnosis and accurate estimation of fetal age. This study evaluated serial transrectal and transabdominal ultrasonography for monitoring embryonic and fetal development in Damascus (Shami) goats (*Capra aegagrus hircus*) (n = 7 carrying to term, including 4 singleton and 3 twin pregnancies). Using 4.0–6.5 MHz linear probes from day 15 to day 128 post-mating, we measured twelve fetal parameters. Placentome diameter, biparietal diameter, occipito-nasal length, thoracic diameter, fetal heart rate, transverse heart diameter, orbit diameter, umbilical cord diameter, and kidney diameter all yielded strong correlations with gestational age (R^2= 0.98–0.99), allowing construction of reliable regression equations. Embryonic vesicle diameter, crown-rump length, and amnion vesicle diameter provided insufficient data for modelling. Maternal serum progesterone (ELISA) remained higher in twin than in singleton pregnancies ($P < 0.001$), with significant differences emerging on days 51, 107, 114 and 128 ($P < 0.05$). Progesterone levels correlated negatively with birth weight. Ultrasonographic fetometry offers a practical, breed-specific tool for gestational dating in goats, and progesterone measurement can assist litter size assessment during specific gestational windows.

Keywords: Caprine gestation; Fetal biometry; Progesterone; Reproductive ultrasonography; Saanen goat; Pregnancy diagnosis.

الملخص

ان إدارة التكاثر في قطعان الماعز الحلوب تعتمد بشكل كبير على التشخيص في الوقت المناسب للحمل والتقدير الدقيق لعمر الجنين. قيّمت هذه الدراسة استخدام التصوير بالموجات فوق الصوتية عبر المستقيم وعبر البطن بشكل متسلسل لمتابعة تطور الأجنة والجنين في ماعز الدمشقي (الشامي) (Capra aegagrus hircus) (عدد = 7 حالات حمل حتى الولادة، منها 4 حمل مفرد و3 حمل توأمي). باستخدام مجسات خطية بتردد 4.0–6.5 ميغاهرتز من اليوم 15 إلى اليوم 128 بعد التزاوج، تم قياس اثني عشر متغيرًا جنينيًا. وقد أظهر كل من قطر المشيمة (Placentome diameter)، القطر ثنائي القُطْب (Biparietal diameter)، الطول القذالي الأنفي (Occipito-nasal length)، القطر الصدري (Thoracic diameter)، معدل ضربات قلب الجنين (Fetal heart rate)، قطر القلب العرضي للجنين، قطر محجر العين (Orbit diameter)، قطر الحبل السري، وقطر الكلية ارتباطًا قويًا بعمر الحمل (R^2 = 0.98–0.99)، مما سمح ببناء معادلات انحدار موثوقة. في المقابل، لم توفر قياسات قطر الكيس الجنيني، وطول الرأس إلى الردف (Crown-rump length)، وقطر كيس السلى بيانات كافية للنمذجة. كما بقي مستوى هرمون البروجستيرون في مصل الأم (ELISA) أعلى في الحمل التوأمي مقارنة بالحمل المفرد ($P < 0.001$)، مع ظهور فروق معنوية في الأيام 51 و107 و114 و128 ($P < 0.05$). وارتبطت مستويات البروجستيرون بعلاقة عكسية مع وزن المواليد عند الولادة. وتشير النتائج إلى أن القياسات بالموجات فوق الصوتية للأجنة تمثل أداة عملية ومحددة للسلالة لتحديد عمر الحمل في الماعز، كما يمكن لاختبار البروجستيرون أن يساعد في تقدير عدد الأجنة خلال فترات معينة من الحمل.

الكلمات المفتاحية: الحمل في الماعز ؛ القياسات الحيوية للجنين؛ هرمون البروجستيرون؛ التصوير بالموجات فوق الصوتية التناسلية؛ ماعز السانين؛ تشخيص الحمل.

Introduction

Farming of goats is an integral part of livestock farming operations in Libya, especially in arid and semi-arid areas, since environmental factors hinder other livestock from being productive. One such breed used for milk production and betterment of genetics is Damascus (Shami) goat (Capra aegagrus hircus), which has become increasingly popular in recent times due to its prolific nature, high milk production potential, and adaptability to Mediterranean/North African conditions. Breeding Damascus goats is now common in Libya, as their crossbreds are increasingly being used in order to improve milk production and herd performance. Nevertheless, there is lack of proper reproductive management procedures, especially concerning the detection of pregnancy status and estimation of gestation length in many farms in Libya. Diagnosis of early pregnancy is very important for proper herd management due to its ability to diagnose open does for rebreeding, nutrition of pregnant goats, and estimation of kidding date. Moreover, determination of litter sizes could help with managing complicated pregnancies and minimizing losses during birth. Various tests have been used for pregnancy diagnosis in goats, which include manual abdominal palpation, hormonal detection, ultrasonography Doppler examination, and X-ray imaging. Nonetheless, these methods suffer from issues related to accuracy, need for laboratory services, or availability in specific gestation periods (Medan & Abd El-Aty, 2010; Erdogan, 2012; Alhadad, 2018). Many research papers have proven that ultrasonography is a better pregnancy diagnosing technique than the other tests, especially during early pregnancy (Padilla-Rivas et al., 2005; Koker et al., 2012; Philip et al., 2017).

In fact, real-time B-mode ultrasonography has been recommended for use in the reproductive examination of small ruminants since it is non-invasive, fast, repeatable, and able to offer visual representation of the embryo and fetus (Vinoles-Gil et al., 2010; Wojtasiak et al., 2020). This procedure has been used successfully in pregnancy diagnosis, fetal counting, embryonic viability, and the assessment of fetal development in different breeds of goats (Suguna et al., 2008; Karen et al., 2014; Samir et al., 2016). Investigations on Damascus goats have shown that transabdominal ultrasound is useful in pregnancy and fetal number diagnosis in gestating dams (Abdelghafar et al., 2009; Roukbi, 2013; (Aloraibi, et al., 2025). In addition, there have been studies which have proven the usefulness of both transrectal and transabdominal ultrasonography in pregnancy diagnosis (Ali et al., 2020; Azizunnesa et al., 2019).

Apart from pregnancy diagnosis, ultrasonography facilitates sequential examination of fetal growth using indices like crown rump length, biparietal diameter, placentome diameter, uterine diameter, thoracic diameter, femur length, and fetal heart dimensions. These indices have previously been used to predict gestational age as well as fetal growth in goats (Amer, 2010; Kumar et al., 2015; Wojtasiak et al., 2020). Many authors have found significant relationships between the measurement of the aforementioned ultrasonic fetal dimensions and gestational age, thus facilitating the establishment of prediction equations for various types of goats (Karen et al., 2009; Abdelghafar et al., 2012; Kuru et al., 2018). Fetal measurements using ultrasonography involving long bone length (femur and humerus) have proven efficient in estimation of gestational age in both mid and late pregnancy periods (Abdelghafar et al., 2012). In addition, placentome size and uterine diameter are considered important predictors of gestational age in the second and third trimesters (Doizé et al., 1997; Muhammad & Aziz, 2021; Asanousi Lamma et al., 2018).

Several goat breeds such as Saanen, Boer, Beetal, Jamnapari, Egyptian native, Abaza, Gurcu, and Shami goats have been investigated for gestational age determination (Karen et al., 2009; Abubakar et al., 2016; Kumar et al., 2015; Kuru et al., 2018; Muhammad & Aziz, 2022). Nonetheless, most existing prediction formulas were generated based on particular management systems and environmental conditions. Thus, the use of these methods to estimate gestational age in Damascus (Shami) goats raised in Libya is still questionable since fetal growth rate differs from one breed to another based on genetics, maternal nutrition, litter size, and environmental impact (Amer, 2010; Erdogan, 2012; Wojtasiak et al., 2020). Additionally, there is evidence showing disparities between the reliability of transrectal, transvaginal, and transabdominal ultrasound imaging to detect pregnancy and age the embryo (Mali et al., 2019; Koker et al., 2012; Philip et al., 2017).

Progesterone is one of the main hormones that play an important role in pregnancy development and maintenance, and can offer additional insight into the physiological state of reproduction. Even though higher levels of progesterone usually indicate a successful pregnancy, the connections between the progesterone levels in pregnant females, litter sizes, fetal development, and birth weights are not sufficiently explored. The usage of progesterone testing for pregnancy verification is quite widespread; however, there are very few works where the combination of hormonal analysis and ultrasonographic fetometry is applied (Medan & Abd El-Aty, 2010).

Although the importance of the Damascus (Shami) goat in Libya is increasing, breed-specific information related to the ultrasound characteristics of fetal development and gestational age determination is still scant. While there is literature on the diagnosis of pregnancy and fetal biometry in Damascus goats (Abdelghafar et al., 2009; Roukbi, 2013), no information is available concerning the relationship between fetal biometry, placental development, gestational age, and the progesterone profile of the dam under Libyan management conditions. Additionally, no information is available on the usefulness of the fetal and placental biometry for prediction of the gestational age. Hence, the aim of this study was to develop gestational age prediction equations using fetal ultrasound measurement, describe the maternal progesterone profiles during gestation, and examine the association between progesterone level, litter size, fetal growth, and birth weight in Damascus goats raised in Libya.

Literature Review

Ultrasound scanning is now the gold standard for detecting and monitoring pregnancy in goat since it allows prompt, noninvasive, and accurate reproductive diagnosis. Several investigations have confirmed the superiority of ultrasound diagnostics in comparison with the conventional diagnostic techniques including vaginal cytology, hormone tests, and behavioral examination (Ali et al., 2020; Azizunnesa et al., 2019; Medan & Abd El-Aty, 2010). Nevertheless, ultrasound scanning efficiency depends on the particular period of pregnancy, ultrasonography route used, fetal position, and the level of professional skills of an examiner. A number of comparative studies have proved that transvaginal and transrectal ultrasound scanning techniques are superior at the beginning of pregnancy, while transabdominal ultrasound scanning is more efficient at the mid- and end-of-pregnancy stages (Koker et al., 2012; Philip et al., 2017; Mali et al., 2019; Padilla-Rivas et al., 2005). Based on these results, it can be noted that ultrasonographic procedures have to be matched with gestational stage rather than uniformly applied during pregnancy.

The use of ultrasound technology is no longer limited to the detection of pregnancy but has been extended to biometry of the fetus as well as its gestational age. Research conducted with various types of goats including Saanen, Beetal, Jamnapari, Abaza, Gurcu, Egyptian native and Damascus goats revealed highly significant correlations between gestational age and various biometrics of the fetus including crown rump length, biparietal diameter, femur length, humerus length, uterine diameter and placental diameter (Doizé et al., 1997; Karen et al., 2009; Abdelghafar et al., 2012; Kuru et al., 2018; Kumar et al., 2015; Abubakar et al., 2016). It is noteworthy, however, that variations were recorded across breeds implying a genetic and environmental impact on fetal growth.

Studies carried out in Damascus (Shami) goats have yielded some important breed-specific information. The study carried out by Abdelghafar et al. (2009) and by Roukbi (2013) proved that the technique of transabdominal ultrasonography could be used successfully for pregnancy diagnosis and fetal enumeration. The model created by Muhammad and Aziz

(2021, 2022) for estimating the gestational age involved ultrasonic measurements of the placentome, uterine, and fetal characteristics. Although those studies proved strong correlations between ultrasonic parameters and gestational age, they also stressed the necessity to validate those methods in specific populations. The same point has been stressed in other review papers dedicated to caprine ultrasonography (Erdogan, 2012; Vinoles-Gil et al., 2010; Wojtasiak et al., 2020).

Other applications of ultrasonography in addition to estimating gestation age include loss evaluation of the embryo or fetus, estimation of number of fetuses, growth assessment of fetuses, and reproductive status (Samir et al., 2016; Karen et al., 2014; Suguna et al., 2008). Nevertheless, the available literature indicates that no standard equation has been developed to estimate fetus weight from ultrasound measurements of Shami goats raised in different production systems. This necessitates more validations of ultrasonographic fetal growth equations in these goats.

However, in Libya, Damascus (Shami) goats are increasingly gaining popularity for dairy purposes due to the ease with which they can be kept and the high productive potentials associated with the breed. Unfortunately, there is inadequate literature on the growth of the fetus and methods for assessing gestational age via ultrasound in relation to Damascus (Shami) goats managed in Libya. Most of the available scientific articles regarding the use of ultrasound to assess the growth of the fetus in Shami goats have either been carried out in locations other than Libya or have provided inadequate data for the reference. In addition, there has not been a comprehensive study that compares various ultrasonographic parameters in order to determine the effectiveness of each method in predicting gestational age. The relationship between maternal progesterone concentrations, litter sizes, and fetal growth in gestating animals remains inadequately understood. This is partly attributed to the fact that most research studies involved sampling at irregular intervals and began when the fetus was well into its development stage.

Thus, the current study aimed to (a) establish the earliest time point for detecting different structures in the development of the embryo and fetus of the Damascus (Shami) goat using ultrasonography through the transrectal and transabdominal routes; (b) establish regression equations of each measure to gestational age; (c) describe the concentration pattern of serum progesterone during pregnancy; and (d) investigate any difference in serum progesterone level depending on singleton and twin gestations.

Methodology

Research design and animal management. The experimental procedures were conducted in accordance with the guidelines for the care and use of animals in research and were approved by the Scientific Research Ethics Committee of the Faculty of Agriculture, University of Tripoli, Libya. Nineteen nulliparous Damascus (Shami) does, aged 20–29 months and weighing 46–55 kg, were selected from a commercial goat farm in the Tripoli region of Libya. All animals were clinically healthy and maintained under uniform management and feeding conditions throughout the study. Two sexually mature Damascus bucks of proven fertility were used for natural mating.

Synchronization of estrus was carried out through short-term treatment via the insertion of intravaginal sponges containing 20 mg FGA for 6 days. Four days after placing sponges, each doe was subjected to an intramuscular injection of 400 IU eCG/PMSG and 0.075 mg D-cloprostenol. The intravaginal sponges were withdrawn on the sixth day, and fertile Damascus bucks were introduced to the herd 12 h thereafter. Estrus behavior was closely monitored for continuous 24 h, with successful mating occurring within 24 h post-introduction of the buck in 17 of the 19 synchronized females. The day of successful mating was considered the first day of gestation.

Pregnancy status was determined ultrasonographically in 14 pregnant animals. Of those, seven goats eventually aborted at days 58, 65, 74, 79 (three animals), and 86. The remaining seven animals maintained their pregnancies to full term, and four among them conceived to give birth to singleton, while three others conceived and gave birth to twins, thus making a total of 10 fetuses. Does received ad libitum water and a ration adjusted for early and late gestation (Table 1). When weather permitted, animals were turned out to pasture.

Table 1. Composition of gestation rations fed to Damascus (Shami) goats (dry matter basis)

Component	Early Gestation (Days 0–100)	Late Gestation (Last 50 Days)
Dry matter intake (kg/day)	1.60	2.00
Barley straw (%)	45.0	30.0
Concentrate mixture (%)	40.0	50.0
Alfalfa hay (%)	15.0	20.0
Metabolizable energy (Mcal/kg DM)	2.20	2.50
Crude protein (%)	11.0	14.0
Metabolizable protein (%)	7.5	9.5
Rumen degradable protein (%)	2.5	3.5

Ultrasonography. The B mode real-time ultrasound equipment used in the study was a Mindray Bio-Medical Electronics Co., Shenzhen, China machine, fitted with two linear rectal probes of 4.0-6.5 MHz. Transrectal scanning took place between days 15 and 27 at three-day intervals. The rectal probe was lubricated using carboxymethylcellulose gel, inserted in the rectum and moved into position when the urinary bladder was seen. It was then rotated clockwise through 90° and counter-clockwise through 180° to scan the uterine horns to the sides and front of the bladder. Transabdominal scans were conducted from day 30 up to day 128, one week apart. The inguinal area was shaved and gel was applied; the probe was positioned just cranially to the udder and pushed towards the bladder. All scans were made into video files by the MP4 recorder (Orite PMP500, Australia).

Fetal measurements. The following parameters were measured as described in the literature: embryonic vesicle diameter (largest anechoic area in the uterus); crown-rump length (from the top of the skull to the end of the sacrum); amnion vesicle diameter (widest diameter of the amnion-surrounded area); placentome diameter (average of three large placentomes, measured when visible as button-like protrusions or “C”/“O” shapes); biparietal diameter (outer-to-outer distance between parietal bones with symmetrical brain hemispheres and falx cerebri midline visible); occipito-nasal length (from the back of the skull to the tip of the nose); thoracic diameter (widest diameter of the rib cage); fetal heart rate (beats counted over 15 seconds and multiplied by 4); transverse heart diameter (four-chamber view during diastole); orbit diameter (widest distance between hyperechoic orbit and hypoechoic eyeball); umbilical cord diameter (average of two measurements: at the fetal body wall and 1 cm further along the cord); kidney diameter (hypoechoic border with anechoic pelvis).

Blood sampling and progesterone assay. The blood was obtained from the jugular vein by vacuum tube with gel coating. The sampling was done daily during days 15 to 24, and later during each day of ultrasound examination days 27-128. Blood samples were left to coagulate, and the serum was isolated by centrifuging at 2000 rpm for 20 min. Samples were kept at -20°C until analysis. Progesterone concentration was assessed using a commercially available ELISA kit (DRG EIA1561, USA).

Statistical analysis. Normality was assessed using the Shapiro Wilk test. For the analysis of Singleton vs. twins, Student’s t test and Mann Whitney U test were used where data were normally and abnormally distributed respectively. Linear regression and quadratic regression were carried out to assess the relationship of fetal parameters with gestational age, and the better fit was chosen depending on r^2. Progesterone analysis among days was done using the Friedman test, followed by the Nemenyi test. Spearman’s rank correlation was performed to measure the relationship between mean maternal progesterone levels and birth weight. Statistical significance was set at $p < 0.05$.

Results

Of the 17 does that showed estrus and mated, 14 became pregnant (82.4% conception rate). Abortion occurred in 7 of these 14 (50% pregnancy loss), leaving 7 does that kidded normally. Among these, 4 carried singletons and 3 carried twins, giving a kidding rate of 1.42 kids per doe and a twinning rate of 42.85%. The first ultrasonographic sign of pregnancy—the embryonic vesicle—was detected in 2 does on day 15, in 5 does on day 18, in 12 does on day 21, and in all 14 pregnant does by day 24.

No statistically significant differences were found between singleton and twin fetuses for any of the measured parameters ($P > 0.05$). Consequently, data from all fetuses were pooled for regression analysis.

Embryonic vesicle diameter (EVD). Figure 1 shows a typical image of the embryonic vesicle at day 30 of gestation. Measurable from day 21 to day 30, after which the vesicle no longer fit within the ultrasound field. Values ranged from 5 mm (day 21) to 30 mm (day 30). Insufficient data points (only 4 measurement days) prevented construction of a regression equation.

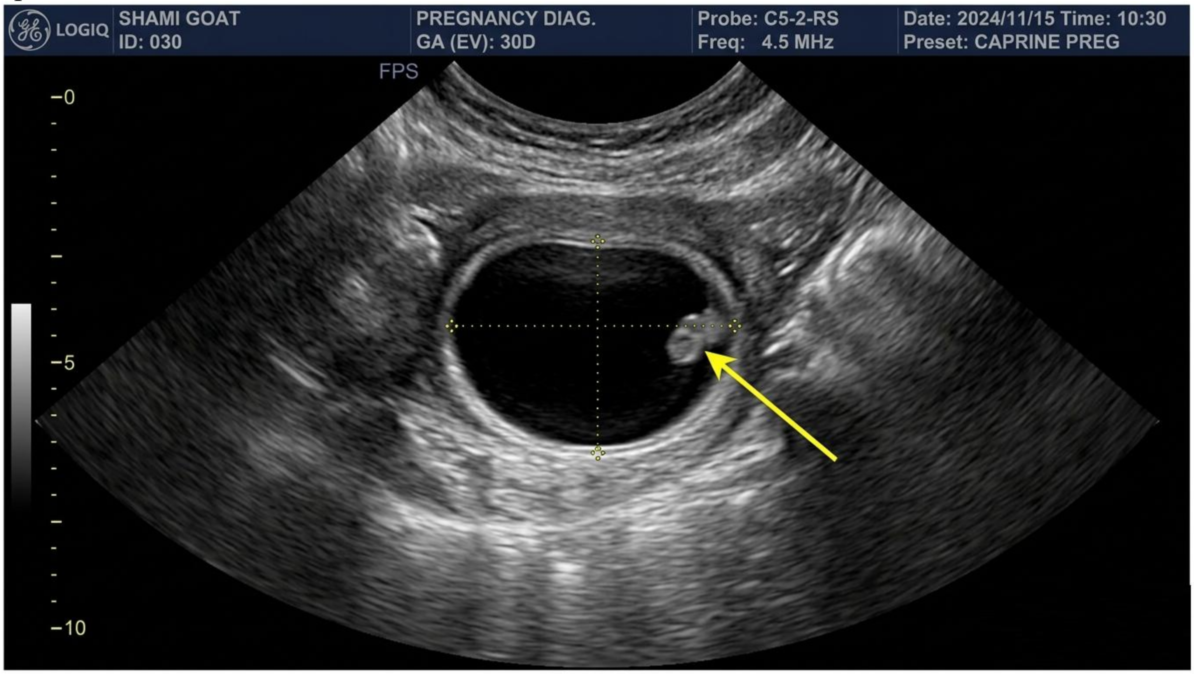

Figure 1. Transabdominal ultrasonogram at day 30 of gestation showing the embryonic vesicle

Crown-rump length (CRL). Figure 2 illustrates crown-rump length measurement at day 37. Measured from day 27 to day 44, values ranged from 8 mm (day 27) to 44 mm (day 44). Only 4 measurement days yielded usable data, so no regression model was fitted.

Amnion vesicle diameter (AVD). Measured on days 30, 37 and 44 only. Values ranged from 15 mm (day 30) to 35 mm (day 44). Data insufficient for regression.

Placentome diameter (PD). A representative placentome image at day 79 is presented in Figure 3. First measurable on day 30 and remained quantifiable until day 121. After day 121, fetal compression distorted normal placentome morphology. The quadratic model provided the best fit: $PD = -18.918 + 0.899 \times GA - 0.004 \times GA^2$ ($R^2 = 0.99$), where GA = gestational age in days. PD increased from approximately 5 mm at day 30 to 28 mm at day 121.

Biparietal diameter (BPD). Figure 4 shows the biparietal diameter measurement at day 65. First measurable on day 37 and recorded until day 107, beyond which the skull no longer fit

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the screen. Linear regression: BPD = –12.218 + 0.525 × GA (R^2= 0.99). BPD rose from about 8 mm at day 37 to 45 mm at day 107.

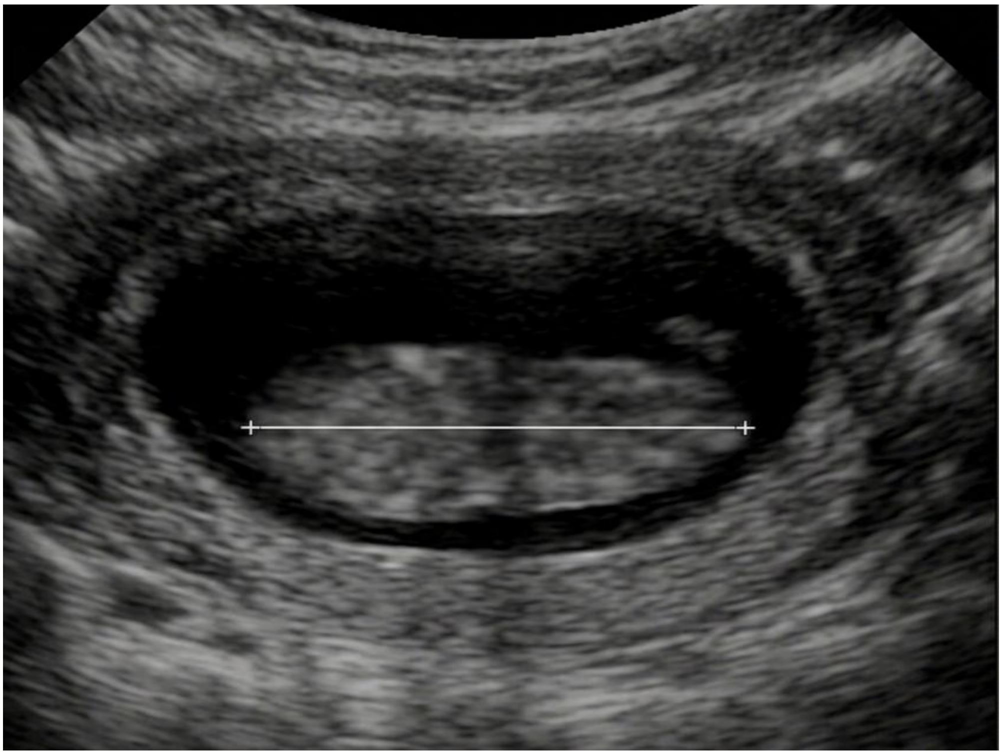

Figure 2. Transabdominal ultrasonogram at day 37 of gestation.

Occipito-nasal length (ONL). Measured from day 37 to day 74. Linear model: **ONL = –30 + 1.07 × GA** (R^2= 0.99). ONL increased from approximately 10 mm at day 37 to 50 mm at day 74.

Thoracic diameter (TD). Measured from day 37 to day 86. Quadratic model: TD = –26.337 + 1.125 × GA – 0.004 × GA^2 (R^2= 0.99). TD ranged from about 12 mm at day 37 to 45 mm at day 86.

Fetal heart rate (FHR). First detected on day 27 but reliably countable only from day 37 onwards. Quadratic model: FHR = 223.409 + 0.452 × GA – 0.007 × GA^2 (R^2= 0.98). FHR decreased from approximately 210 bpm at day 37 to 150 bpm at day 128.

Transverse heart diameter (THD). First clearly measurable on day 44; continued to day 128. Quadratic model: THD = –4.47 + 0.127 × GA + 0.001 × GA^2 (R^2= 0.99). THD rose from about 5 mm at day 44 to 22 mm at day 128.

Orbit diameter (OD). Figure 5 presents orbit measurement at day 58. Measured from day 44 to day 128. Linear model: OD = –5.488 + 0.218 × GA (R^2= 0.99). OD increased from approximately 5 mm at day 44 to 22 mm at day 128.

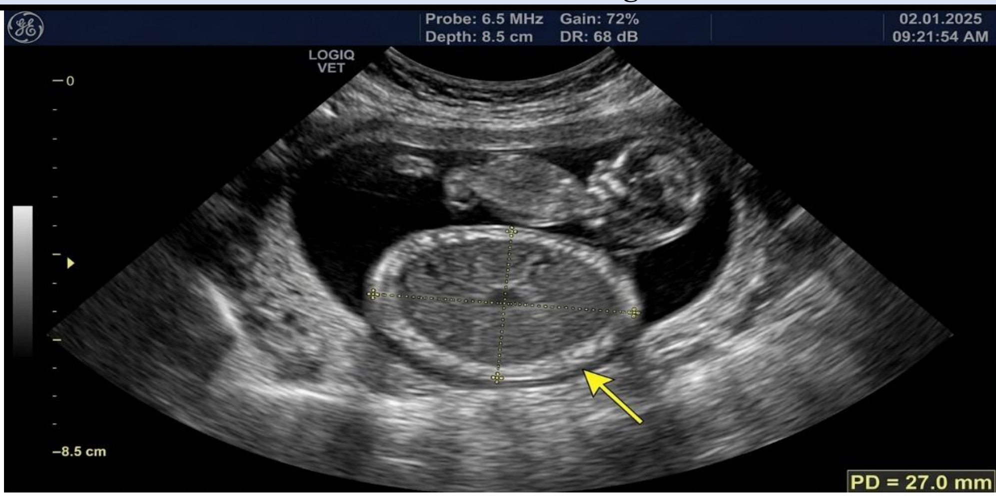

Figure 3. Transabdominal ultrasonogram at day 79 of gestation.

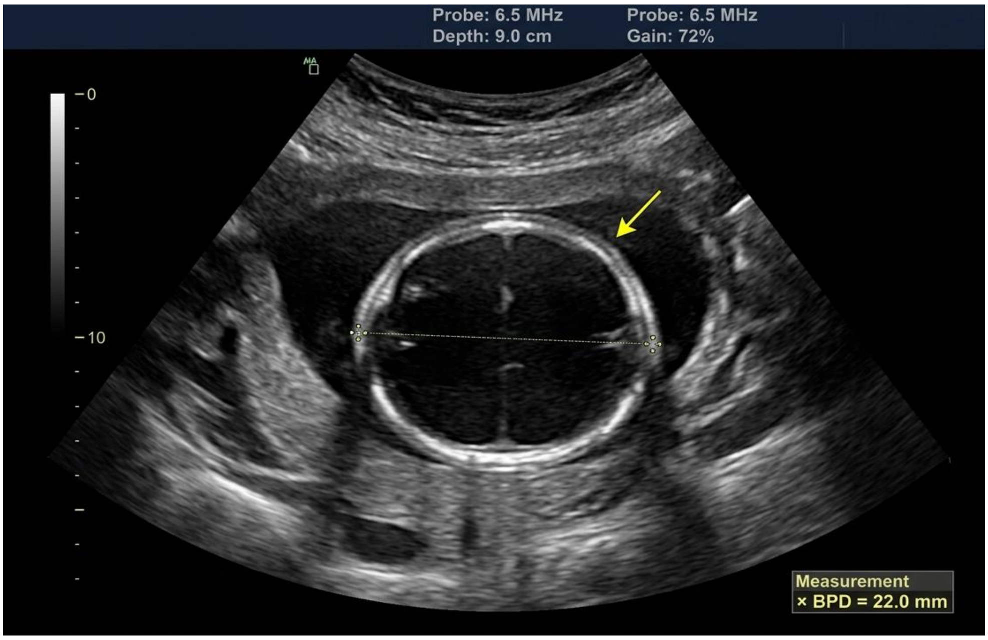

Figure 4. Transabdominal ultrasonogram at day 65 of gestation

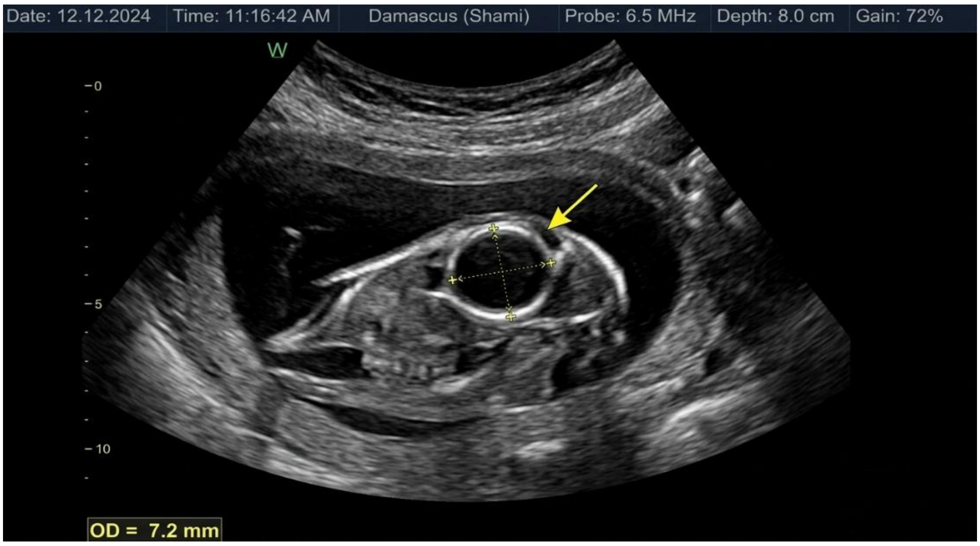

Figure 5. Transabdominal ultrasonogram at day 58 of gestation

Umbilical cord diameter (UCD). Measured from day 51 to day 121. Linear model: **UCD = –** 3.018 + 0.131 × GA (R^2= 0.98). UCD increased from about 4 mm at day 51 to 13 mm at day 121.

Kidney diameter (KD). First measurable on day 93 and continued to day 128. Linear model: KD = –13.964 + 0.364 × GA (R^2= 0.98). KD increased from about 20 mm at day 93 to 33 mm at day 128.

Table 2 summarizes all regression equations and their goodness-of-fit.

Table 2. Regression equations for fetal parameters against gestational age (GA in days) in Damascus (Shami) goats

Parameter	Regression model	Equation	GA range (days)	R^2
Placentome diameter (mm)	Quadratic	–18.918 + 0.899×GA – 0.004×GA²	30–121	0.99
Biparietal diameter (mm)	Linear	–12.218 + 0.525×GA	37–107	0.99
Occipito-nasal length (mm)	Linear	–30 + 1.07×GA	37–74	0.99
Thoracic diameter (mm)	Quadratic	–26.337 + 1.125×GA – 0.004×GA²	37–86	0.99
Fetal heart rate (bpm)	Quadratic	223.409 + 0.452×GA – 0.007×GA²	37–128	0.98
Transverse heart diameter (mm)	Quadratic	–4.47 + 0.127×GA + 0.001×GA²	44–128	0.99
Orbit diameter (mm)	Linear	–5.488 + 0.218×GA	44–128	0.99
Umbilical cord diameter (mm)	Linear	–3.018 + 0.131×GA	51–121	0.98
Kidney diameter (mm)	Linear	–13.964 + 0.364×GA	93–128	0.98

Progesterone profiles. Mean serum progesterone concentration in the 14 pregnant does between days 15 and 24 ranged from 13.39 ± 1.18 ng/mL (day 15) to 17.63 ± 1.88 ng/mL (day 21). Among the 3 mated but non-pregnant does, one showed a sharp progesterone decline below 1 ng/mL by day 20, whereas the other two maintained elevated levels similar to pregnant does until day 24, suggesting persistent corpora lutea from non-fertile cycles.

When comparing singleton (n=4) vs. twin (n=3) pregnancies across the entire gestation, progesterone was consistently higher in twin pregnancies ($P < 0.001$). Day-by-day analysis revealed significant differences on days 51, 107, 114 and 128 ($P < 0.05$). Within singletons, progesterone fluctuated significantly across days (Friedman, $P < 0.05$), with notable peaks on day 100 (median 18 ng/mL) and a sharp drop after day 107. In twins, progesterone rose gradually, reaching a peak median of 23.33 ng/mL on day 114, and remained near that level until the end of the study.

Birth weight and progesterone correlation. Singleton kids weighed 4.09 ± 0.05 kg at birth, while individual twin kids weighed 3.35 ± 0.09 kg ($P < 0.05$ for singleton vs. individual twin). The combined litter weight for twins averaged 6.7 ± 0.21 kg. Across all kids, maternal progesterone concentration (mean of all gestational measurements for each dam) correlated negatively with birth weight (Spearman's $\rho = –0.71$, $P < 0.05$).

Discussion

This study offers breed-specific reference equations on biometrics of fetus from Damascus (Shami) goats reared in Libya. This helps fill the existing gap on reproductive aspects in caprines, which is crucial in veterinary science. The fact that the coefficients of determination were quite high for many biometric measures (R^2 = 0.98 to 0.99) shows the efficacy of ultrasonic fetometry for gestational age prediction and is consistent with results obtained from Shami goats, Egyptian native breed, Saanen goats, Jamnapari goats, among others (Doizé et al., 1997; Karen et al., 2009; Abdelghafar et al., 2012; Kuru et al., 2018; Muhammad & Aziz, 2022).

The first recognition of the vesicle on day 15 and the complete confirmation of pregnancy on day 24 is aligned with the literature that ultrasonography is highly accurate means for the diagnosis of early pregnancy between days 20 to 25 after conception (Padilla-Rivas et al., 2005; Suguna et al., 2008; Koker et al., 2012; Philip et al., 2017). Although earlier diagnosis has been observed under experimental conditions, the probable cause for this difference in results can be attributed to the frequency of the probe used, the scanning technique, and interval between examinations.

Among all the parameters considered, the size of the placental lobes emerged as the most precise predictor of the gestational period. Similar results have also been obtained in sheep and goats, where a correlation between the size of placental lobes and the age of the fetus was found during the entire gestation period (Doizé et al., 1997; Karen et al., 2009; Muhammad & Aziz, 2021). However, it is necessary to note that the measurement of the placental lobes size was progressively more difficult with each passing day because of the growth of the fetus and uterus compression. The same issues arose when measuring the gestational age of other breeds of goats (Suguna et al., 2008; Kumar et al., 2015).

The linear relationship between the biparietal diameter and the occipito-nasal length was strong. Thus, the two measurements may be regarded as valid estimates of the fetal age in mid-gestation and late gestation stages. In this regard, it must be noted that analogous findings have been reported by other authors studying Shami goats, Egyptian native goats, as well as Abaza and Gurcu goats (Karen et al., 2009; Kuru et al., 2018; Muhammad & Aziz, 2022). Possible variations in size measurements may be explained by differing growth among sheep breeds, maternal nutrition, as well as environmental conditions. Findings of the current investigation underscore previous recommendations concerning the need for breed-specific gestational age calculation.

Reducing fetal heart rates with increasing ages is consistent with the findings observed on goats through ultrasounds (Amer, 2010; Wojtasiak et al., 2020) that depict normal fetal cardiovascular system development. While the measurement of the fetal heart rate was characterized by great variation in values at the early stages of gestation, it still remained a valuable index to assess the health status of the fetus during the entire pregnancy period. In addition, while the linear growth pattern of fetal orbit and kidneys experienced variations, the linear growth patterns remained unchanged throughout the whole pregnancy duration. This is because fetal structures become very large and measuring becomes quite difficult as pregnancy progresses. These findings are consistent with those obtained from studies conducted on goats (Amer, 2010; Kumar et al., 2015; Muhammad & Aziz, 2022).

The findings related to progesterone levels in this study indicate the great significance of this hormone in maintaining pregnancy. The high progesterone levels in twin pregnancies observed at middle and advanced stages of gestation might be justified by the size of the placenta and endocrine function, because there is more than one fetus. Although correlations were determined between progesterone concentrations and litter size, overlap in data in both singletons and twins indicates that progesterone cannot be considered a surrogate for ultrasonic examinations in the assessment of the number of fetuses. In addition, correlation between progesterone concentration and birth weight suggests complicated relations between placental development, growth of the fetus, and hormonal processes. This discrepancy was also noted in previous research conducted among goats related to reproduction issues, and more investigations in this field are required (Capezzuto et al., 2008; Salve et al., 2016).

In general, the results of the present research confirm that ultrasonography based fetometry can serve as a valuable instrument for assessing the gestational period of pregnancy in Shami goats. Equations specific for the studied breed will be helpful in reproductive management of Shami goats in Libyan production conditions.

Limitations

A number of caveats should be taken into account in the interpretation of the results obtained in this study. For one thing, the number of does that carried their pregnancy to full-term was relatively low and might have affected the statistical power in comparisons made between singleton and twin pregnancies. While repeated ultrasonographic observations yielded quite an extensive database for use in regression analyses, more numbers need to be involved in order to provide greater validation to the predictive equations formulated for Damascus (Shami) goats. Another limitation to this experiment lies in pregnancy losses occurring in gestating animals, hence affecting the analysis of progesterone concentrations as well as fetal growth parameters in the course of gestation. A further limitation involves ultrasonographic observations conducted only up to 128 days of gestation, hence precluding the assessment of fetal growth in the late gestational periods leading up to birth.

Conclusion

The present work develops specific ultrasound reference formulae for calculating the gestational age of Damascus (Shami) goats under Libyan breeding conditions. Placentome diameter, biparietal diameter, occipito-nasal length, thoracic diameter, transverse heart diameter, orbit diameter, umbilical cord diameter, and kidney diameter showed a strong correlation with the gestational age, indicating great predictability of these parameters at all stages of pregnancy. Of these parameters, orbit diameter and kidney diameter proved especially useful for late pregnancy since they were easily detectable despite the obscuration of large fetal structures due to growth. Concentration of progesterone in maternal blood rose throughout pregnancy and was found to be relatively higher in twin-bearing compared to singleton-bearing goats, especially in late pregnancy. Nonetheless, the high overlap of progesterone values between the pregnancy types makes it impractical to employ the concentrations of progesterone as the sole criterion for assessing the litter size. Correlation between progesterone level and birth weight indicates the interplay of several physiological factors related to placental function and fetal endocrine activity. These results can be used for practical purposes in breeding goats.

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