



THE ROLE OF PLACENTAL DEVELOPMENT IN DETERMINING BIRTH WEIGHT AND GROWTH PERFORMANCE OF LAMBS

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Abstract: The placenta plays a central role in regulating fetal growth and is a key determinant of lamb birth weight and postnatal growth performance. In sheep, variation in placental traits influences not only neonatal outcomes but also subsequent growth trajectories, supporting the concept of developmental programming. This review summarizes current knowledge on major placental traits, including placental weight, cotyledon number, cotyledon size and surface area, and indices of placental efficiency, and evaluates their associations with lamb birth weight and postnatal growth. Evidence indicates that placental mass alone does not adequately reflect placental function, whereas cotyledon-based traits and placental efficiency provide more informative indicators of fetal growth capacity. Relationships between placental traits and growth outcomes are strongly influenced by litter size, dam parity, and breed. This review highlights key knowledge gaps and emphasizes the need for standardized placental phenotyping and integrative research approaches to improve understanding of early-life determinants of growth performance in sheep.

Keywords: Placenta, Placental efficiency, Cotyledon, Lamb growth, Fetal programming, Postnatal performance

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1. Introduction

Fertilization occurs through the fusion of sperm and egg cells. Following fertilization, the first mitotic division takes place 1.5 days after zygote formation (Gordon, 2003). 3-4 days after zygote formation, a cell cluster called a morula, consisting of 12-16 blastomeres and shaped like a mulberry, is formed. The blastomeres forming the morula compress and come together to form a new cell structure resembling a bunch of grapes (Iwasaki et al., 1990). After this phase, called the compression phase, the cells evolve into two different cell clusters: central and outer. The central cells are called the inner cell mass (embryoblast), and these formations later develop into the embryo. The outer cells are called trophoblasts, and these cells eventually come together to form the placenta (Gordon, 2003). Embryoblasts are involved in the formation of the embryo and umbilical cord, while trophoblasts are involved in the formation of embryonic membranes and the placenta (Igwebuike, 2010). The diameter of the chorionic sac begins to increase after the 9th day of embryonic development (Sammin et al., 2009). Implantation is fully completed on the 11th day, and by the 12th day, the embryo is covered with a blood clot. This blood clot is surrounded by an epithelial membrane to form the chorionic sac (Redmer et al., 2004; Konyalı et al., 2004a). The placenta, which consists of fetal and

maternal parts, has a fetal portion composed of the chorionic plate and its attached villi. The maternal portion consists of the basal plate and the placental septum. The fetal surface is called the cotyledon, and the maternal surface is called the caruncle (Konyalı et al., 2004b).

The placental structure, formed by the aggregation of trophoblasts, is an embryonic tissue that surrounds the foetus, protecting it from external factors, providing nourishment, and playing a role in respiration and excretory metabolism, secreting various hormones throughout the embryo's development. A structure specific to pregnancy, the placenta exhibits unique characteristics depending on the species (Konyalı et al., 2006). A temporary organ expelled upon the healthy birth of the foetus, the placenta is vital for the foetus's survival (Igwebuike, 2010). The placenta is an endocrine organ that mediates the transfer of nutrients and oxygen from the mother to the foetus and facilitates the removal of fetal metabolic waste products and carbon dioxide. In addition, it produces and secretes hormones essential for the maintenance of pregnancy, including chorionic gonadotropin, placental lactogen, progesterone, estrogen, and relaxin (Redmer et al., 2004).

The fetal surface of the placenta is smoother and paler than the maternal surface. This appearance is due to its attachment to the amniotic and chorionic membranes (Dağdelen and Esenbuga, 2025). The cotyledons from the



foetus fuse with the caruncles on the maternal side to form the placenta. As the pregnancy progresses, the caruncle crypts develop. With the increase in blood flow to the foetus, the amount of blood flow to the foetus also increases (Wooding et al., 1997; Lee et al., 1997; Konyalı et al., 2007). Placental development in sheep and goats begins with implantation, and the growth phase of the placenta, i.e., placentation, ends around days 50-60 of gestation. In sheep and goats, syndesmochorial type placenta is observed (Lacroix et al., 2002).

In the context of sheep production, the survival rate of lambs, along with their early growth and development performance, assumes a pivotal role in determining flock productivity and economic sustainability. It has been demonstrated that these economic outputs are closely associated with birth weight, survival rates of newborn lambs, colostrum intake, immune status, and growth and development characteristics (Dwyer, 2008; Kenyon et al., 2014; Dagdelen and Esenbuga, 2025). It is well established that lambs born with low birth weight are susceptible to a high risk of mortality during the neonatal period. As demonstrated in the research by Dwyer (2008), low daily live weight gains after birth result in reduced weaning weights and decreased lifetime performance. Consequently, research in the field of ruminant animal science has focused on the parameters determining birth weight and early growth differences.

Birth weight is a complex trait determined not only by genetic makeup but also by a range of maternal, fetal, and environmental factors, including breed, sex, maternal age and parity, litter size, maternal nutrition, and conditions during pregnancy (Kenyon et al., 2014; Toschi and Baratta, 2021). Recent studies have demonstrated that the placenta functions as a highly dynamic interface between the mother and foetus and serves as the primary regulator of foetal growth (Konyalı et al., 2011). Recent studies have demonstrated that the placenta functions as a highly functional interface between the mother and foetus, and is the primary regulator of foetal growth (Konyalı et al., 2011).

Birth weight is a complex trait influenced by genetic makeup, sex, maternal age, number of births, number of offspring, maternal nutrition, and environmental conditions during pregnancy (Kenyon et al., 2014; Toschi and Baratta, 2021). However, beyond these factors, mounting evidence underscores the placenta's role as a functional interface between the maternal and fetal environments, thereby establishing it as the primary regulator of fetal growth (Vonnahme et al., 2003). The transfer of oxygen, glucose, amino acids, fatty acids, minerals, and hormones necessary for the foetus is carried out by the placenta (Reynolds and Redmer, 2001; Vonnahme et al., 2003).

In sheep, the placenta is classified as cotyledonary, with placentomes formed by the interdigitation of maternal caruncles and fetal cotyledons serving as the principal units of maternofetal exchange (Reynolds and Redmer, 2001). Within this structure, numerous placental traits,

including placental weight, the number of cotyledons, cotyledon surface area, placentome morphology, and placental efficiency, have been extensively studied as indicators of the placenta's capacity to support fetal growth (Vonnahme et al., 2003; Şen, 2021). Among these factors, placental efficiency – commonly expressed as the ratio of fetal or birth weight to placental weight – has emerged as a pragmatic metric for evaluating the placenta's capacity to support fetal development in relation to its size (Reynolds et al., 2010; Ashley et al., 2023).

It is evident that the majority of placental growth in sheep takes place during the first two-thirds of gestation. Subsequent to this initial phase, placental mass plateaus, and the resultant fetal growth, are largely contingent on enhanced vascularization, augmented blood flow, and optimised nutrient transport efficiency, as opposed to the mere size of the placenta itself (Reynolds and Redmer, 2001; Vonnahme et al., 2003). The present findings indicate that the developmental pattern of a relatively small but efficient placenta may be sufficient to ensure adequate fetal growth, while a heavier placenta is not necessarily correlated with superior nutrient transfer (Vonnahme et al., 2003; Ashley et al., 2023). Accordingly, studies have reported inconsistent relationships between placental weight alone and lamb birth weight, thus underscoring the necessity of incorporating cotyledonary characteristics and efficiency indices into placental assessments (Ozyurek and Turkyilmaz, 2020; Şen, 2021). A body of literature that has grown considerably over time has demonstrated significant associations between placental traits and lamb birth weight, with these associations being observed across different breeds and management systems. As indicated by the findings of Ozyurek and Turkyilmaz (2020) and Şen (2021), a positive correlation has been demonstrated between the birth weight of lambs, the number of cotyledons, the surface area of the cotyledons and the size of placentomes. These results suggest that structural adaptations of the placenta play a crucial role in determining fetal growth capacity (Ozyurek and Turkyilmaz, 2020; Şen, 2021). Moreover, litter size has been demonstrated to exert significant influence on placental morphology (Vonnahme et al., 2003; Kenyon et al., 2014). Multiple pregnancies frequently result in reduced individual placental mass and altered cotyledon development, consequently leading to reduced birth weights per lamb.

The impact of placental development is not limited to the birth process but extends into the postnatal growth period. This finding lends further support to the concept of fetal or early-life programming. In accordance with the principles outlined in the aforementioned framework, intrauterine conditions exert a permanent influence on physiological functions, metabolic pathways, and growth potential, consequently impacting performance traits in later life (Barker, 2007; Reynolds et al., 2023). In lambs, compromised placental development has been

demonstrated to be associated with reduced birth weight, as well as altered postnatal growth rates, feed efficiency, body composition, and carcass characteristics (Greenwood et al., 2000; Toschi and Baratta, 2021). However, lambs demonstrating compensatory or "catch-up" growth following intrauterine growth restriction (IUGR) have been observed to exhibit altered metabolic profiles. This has led to concerns about the long-term efficiency and robustness of these animals (Greenwood et al., 2000).

At the mechanistic level, the placenta exerts a regulatory influence over fetal growth, which is facilitated through endocrine and molecular pathways, most notably the growth hormone–insulin-like growth factor (GH-IGF) axis. IGF-1 and IGF-2 are key regulators of placental growth, nutrient transport and fetal tissue accretion (Reynolds et al., 2010; Sferruzzi-Perri et al., 2017). Variations in their expression have been linked to differences in placental efficiency and fetal growth outcomes (Reynolds et al., 2010; Sferruzzi-Perri et al., 2017) in ruminants. Despite the growing interest in this area of research, the number of integrative reviews that are specifically focusing on how placental morphology and function are related to birth weight and subsequent growth performance in lambs is still limited.

The objective of the present review is twofold. Firstly, it aims to synthesise existing knowledge on placental traits in sheep and their influence on lamb birth weight and postnatal growth performance. Secondly, it seeks to critically evaluate the underlying biological mechanisms linking placental development and efficiency to fetal growth and early-life performance outcomes. The central aim of this review is to provide a comprehensive framework for understanding the placenta's role in shaping early-life performance and long-term productivity in lambs. This objective is achieved by integrating morphological, physiological, and mechanistic evidence. The review's practical implications extend to breeding strategies and gestational management in small ruminant production systems.

To achieve these objectives, a structured literature review was conducted using major scientific databases, including Web of Science, Scopus, and Google Scholar. Peer-reviewed articles published primarily between 2000 and 2024 were considered, with particular emphasis on studies addressing placental morphology, placental efficiency, fetal programming, and postnatal growth performance in sheep. Relevant publications were selected based on their scientific relevance, methodological rigor, and direct contribution to understanding the role of placental traits in lamb growth and productivity.

2. Key Placental Traits Used in Sheep Researches

The evaluation of placental function in sheep has traditionally relied on a set of quantifiable morphological

and derived traits, which reflect the placental capacity to support fetal growth. The aforementioned traits enable the indirect assessment of nutrient and oxygen transfer efficiency, thereby providing a practical framework for the linkage of intrauterine development with lamb birth weight and subsequent growth performance (Reynolds and Redmer, 2001; Vonnahme et al., 2003; Ozyurek and Turkyilmaz, 2020; Dagdelen and Esenbuga, 2025). As demonstrated in extant literature, the most frequently reported metrics include placental weight, cotyledon number, cotyledon size, surface area, and indices of placental efficiency.

2.1. Placental Weight

The measurement of placental weight constitutes a fundamental element in a multitude of studies that investigate fetal growth in sheep. This parameter has gained prominence due to its ease of measurement and its assumed correlation with the functional capacity of the placenta (Reynolds et al., 2010). It has been established that placental weight is generally indicative of the cumulative growth of placentomes throughout gestation, thus serving as a proxy for the size of the maternofetal exchange interface (Vonnahme et al., 2003; Dagdelen and Esenbuga, 2025).

Numerous studies have indicated a positive correlation between placental weight and lamb birth weight, implying that larger placentas may facilitate enhanced nutrient supply to the foetus (Ozyurek and Turkyilmaz, 2020; Şen, 2021). Nevertheless, it is important to note that this relationship is not invariably linear or consistent across various breeds, litter sizes, and management systems. In multiple pregnancies, for instance, the placental weight per foetus is commonly reduced, although fetal growth can be partly sustained through structural and functional adaptations (Reynolds and Redmer, 2001; Kenyon et al., 2014).

It is important to note that the placental weight alone does not provide a definitive reflection of its efficiency or its capacity for nutrient transfer. A placenta that is comparatively heavy may demonstrate low functional efficiency; conversely, a placenta of a lesser mass may engender adequate fetal growth through such processes as enhanced vascularization or transporter activity (Vonnahme et al., 2003; Ashley et al., 2023). As a consequence, reliance on the placental weight metric exclusively may result in the concealment of biologically significant variation in placental function.

2.2. Number of Cotyledons

In sheep, placentomes are considered the fundamental functional units of the placenta. It has been determined that the number of cotyledons is a significant factor in determining the total exchange surface available for maternofetal transfer (Reynolds and Redmer, 2001). The totality of cotyledons is predominantly determined during the initial stages of foetal development and is subject to the influence of genetic composition, parity of the mother, the capacity of the uterus, and the size of the litter (Vonnahme et al., 2003; Dagdelen and Esenbuga,

2025).

Numerous studies have reported a positive relationship between cotyledon number and lamb birth weight (Ozyurek and Turkyilmaz, 2020; Şen, 2021; Dagdelen and Esenbuga, 2025), indicating that a greater number of placentomes may enhance fetal nutrient supply. In the case of multiple pregnancies, it has been posited that adaptive increases in the number of cotyledons per foetus represent a compensatory mechanism aimed at counterbalancing reduced placental mass (Reynolds et al., 2010).

It has previously been documented that breed-specific variations in cotyledon number have been observed. This finding offers support for the hypothesis that genetic variation in placental development strategies exists among indigenous and improved sheep breeds (Kenyon et al., 2014). It is suggested that these differences may provide some degree of explanation for the observed variations in birth weight and neonatal robustness across breeds, even in cases where the environmental conditions to which they are exposed are similar.

2.3. Cotyledon Size and Surface Area

It has been determined that, in addition to the number and size of the cotyledons, the surface area of these organs is a critical determinant of the functional capacity of the placenta. It has been demonstrated that larger cotyledons, which possess an enhanced surface area, serve to improve the interface for both nutrient and gas exchange. This, in turn, provides a vital foundation for supporting fetal growth, a particularly significant factor during the latter stages of gestation when demands on nutrients and other essential substances by the foetus are at their most rapid (Reynolds and Redmer, 2001; Vonnahme et al., 2003).

Research has indicated that the surface area of the cotyledons may be a more significant determining factor in the birth weight of lambs than the weight of the placenta alone. This underscores the critical role of placental microstructure in regulating fetal growth (Şen, 2021). The measurement approaches employed in extant studies vary significantly, ranging from rudimentary diameter and weight assessments to more sophisticated morphometric analyses, a methodological discrepancy which to some extent contributes to the inconsistencies observed in reported associations.

A correlation between cotyledon number and size has been observed in certain studies, thus indicating the existence of divergent placental strategies that may be adopted to ensure adequate exchange capacity (Ashley et al., 2023). Such structural adaptations are indicative of the adaptive nature of the sheep placenta in response to maternal and fetal constraints.

2.4. Placental Efficiency

The concept of placental efficiency, defined as the ratio of lamb birth weight to placental weight, has attracted mounting attention as a functional indicator of placental performance (Konyalı et al., 2007; Reynolds et al., 2010). It can be posited that this index provides a reflection of

the effectiveness with which the placenta provides support for foetus growth relative to its size. Furthermore, it offers insight into placental adaptations that are not captured by measurements of absolute weight (Konyalı et al., 2007; Dagdelen and Esenbuga, 2025).

It is well-documented that high placental efficiency is associated with adequate fetal growth, even when the placental mass is comparatively reduced. This phenomenon is particularly prevalent in cases of multiple pregnancies or in circumstances where the maternal nutrient supply is limited (Vonnahme et al., 2012; Ashley et al., 2023). On the other hand, low placental efficiency may be indicative of impaired nutrient transfer capacity, even in the presence of a large placenta (Ozyurek and Turkyilmaz, 2020).

Interpretation of placental efficiency, however, necessitates caution, as elevated values may be indicative of compensatory responses to intrauterine growth restriction, which can have ramifications for postnatal growth patterns and metabolic function (Greenwood et al., 2000; Reynolds et al., 2023).

3. Associations between Placental Traits and Lamb Birth Weight

The immediate phenotypic outcome that can be observed at birth with respect to the development and function of the placenta is that of the birth weight of lambs. It is evident that the placenta is the sole organ responsible for mediating the exchange of nutrients, oxygen, and endocrine factors between the dam and the foetus (Reynolds and Redmer, 2001; Vonnahme et al., 2003). Consequently, variations in placental morphology and efficiency are inevitably reflected in foetal growth and birth weight. Therefore, a considerable number of studies have been conducted to investigate the extent to which measurable placental traits can predict lamb birth weight across different breeds, litter sizes, and production systems.

In the field of placental research, the examination of placental weight has been the most prevalent parameter of study, particularly in relation to the birth weight of lambs. Numerous studies have indicated a positive correlation between placental weight and birth weight, thereby lending support to the hypothesis that the placenta, by virtue of its size and capacity, facilitates enhanced exchange processes conducive to optimal fetal development (Ozyurek and Turkyilmaz, 2020; Şen, 2021; Turkyilmaz and Esenbuga, 2022). Nevertheless, the strength and consistency of the relationship are subject to wide variation, thus indicating that placental mass is an incomplete predictor of fetal growth.

Conversely, cotyledon-based traits, encompassing cotyledon number and surface area, have frequently demonstrated stronger and more consistent correlations with birth weights. It has been established that an increased number of cotyledons enhances the total

placentome surface available for maternofetal exchange, thereby supporting greater fetal growth potential (Reynolds et al., 2010; Vonnahme et al., 2003). Furthermore, it has been demonstrated that increased cotyledon size and surface area are correlated with enhanced birth weights, particularly during the latter stage of gestation, when fetoplacental nutrient demands experience a marked increase (Şen, 2021).

More recently, placental efficiency indices have attracted interest due to their potential as integrative indicators of birth weight. High placental efficiency has been shown to be associated with adequate, and in some cases high, birth weights despite relatively small placental mass, indicating functional adaptations that optimize the transfer of nutrients (Ashley et al., 2023). These findings emphasize the necessity of evaluating placental traits in conjunction with one another, as opposed to undertaking this evaluation in isolation.

3.1. Placental Traits and Postnatal Growth Performance in Lambs

While lamb birth weight is the most immediate and readily observable outcome of placental development, there is mounting evidence that placental traits exert a significant influence that extends beyond parturition, playing a pivotal role in determining postnatal growth trajectories. This viewpoint is congruent with the notion of developmental, or fetal, programming, which postulates that in utero conditions engender enduring repercussions on physiological regulatory mechanisms, metabolic functionality, and developmental potential in the postnatal period (Barker, 2007; Reynolds et al., 2023). In this specific context, the placenta fulfils not only the function of facilitating fetal growth during gestation; it also operates as a biological mediator, exerting an influence on the course of postnatal performance (Konyali et al., 2007).

In sheep subjects, disparities in placental morphology and functional efficiency have been linked to variations in birth weight as well as to growth rate, robustness, and productive performance during both the pre- and post-weaning periods. Research findings indicate that lambs from pregnancies featuring higher placental efficiency or more favourable placentome development frequently demonstrate superior early growth rates, heightened vitality, and elevated resilience to environmental stressors (Greenwood et al., 2000; Konyali et al., 2011; Toschi and Baratta, 2021). In contrast, compromised placental development has been linked to reduced physiological maturity at birth, which may result in slower initial growth and increased vulnerability to health challenges in lambs.

Evidence derived from studies conducted on ovine subjects offers further indication that placental constraints experienced during the gestational period can exert a lasting effect on postnatal growth regulation. Konyali et al. (2007; 2011) have demonstrated the influence of prenatal growth conditions on subsequent growth performance, body development patterns and

efficiency traits in lambs. This supports the view that intrauterine factors contribute to long-term variability in productivity. The present findings are in accordance with broader observations that lambs experiencing suboptimal placental support may rely more heavily on compensatory growth mechanisms after birth, which do not necessarily result in equivalent productive outcomes. The initial phase of postnatal development (birth to weaning) represents a critical juncture during which the influences of the placenta on foetal development persist. Offspring from placentas exhibiting superior functional capacity, as indicated by an augmented cotyledon surface area or enhanced placental efficiency, have been observed to demonstrate enhanced early growth rates and elevated survival rates during the neonatal phase (Greenwood et al., 2000; Toschi and Baratta, 2021). Numerous research studies have documented a favourable relationship between placental weight or number of cotyledons, as measured from birth to weaning, and average daily gain. These findings imply that the placenta plays a pivotal role in facilitating physiological development during gestation, contributing to enhanced maturity at birth (Ozyurek and Turkyilmaz, 2020; Şen, 2021). However, lambs whose placentas have a reduced capacity to exchange nutrients often exhibit diminished early growth rates and elevated susceptibility to environmental stressors, even when postnatal management conditions remain constant.

It is crucial to acknowledge that postnatal growth responses are not fully explained by birth weight alone. It has been demonstrated that lambs with comparable birth weights but divergent placental development histories, including differing placental efficiency indices, may follow disparate growth trajectories during the suckling period (Greenwood et al., 2000; Reynolds et al., 2023). These variations are indicative of discrepancies in organ development, muscle fibre number, endocrine sensitivity and metabolic programming established during gestation. Such disparities in growth efficiency and carcass characteristics may be attributable to the interaction between prenatal programming and postnatal management practices, with some lambs demonstrating superior feed efficiency and carcass characteristics, while others exhibit altered body composition or reduced growth efficiency despite comparable postnatal management.

The findings, taken collectively, emphasize that placental traits represent a crucial, albeit frequently neglected, determinant of postnatal growth performance in sheep. The placenta, when recognized as a catalyst for both prenatal and early postnatal development, facilitates the establishment of a more integrated framework for the comprehension of variability in lamb growth and productivity. This underscores the necessity of incorporating placental indicators into research endeavors investigating early-life performance and lifetime efficiency.

3.2. Post-Weaning Growth and Long-Term Performance

The present investigation explores how placental development influences growth performance, with a focus on how these influences persist beyond weaning. The study seeks to elucidate how placental development affects growth efficiency during the post-weaning and fattening periods, offering novel insights into the dynamics of post-weaning development in farm animals. Evidence derived from ovine studies indicates that placental insufficiency experienced during gestation can result in alterations in muscle fibre development, endocrine function and nutrient utilization, which may consequently constrain growth potential in later life (Reynolds et al., 2023; Toschi and Baratta, 2021).

It has been reported that lambs originating from pregnancies characterized by reduced placental mass or low placental efficiency have been shown to exhibit lower growth rates during the growing and finishing phases, even when adequate postnatal nutrition is provided (Greenwood et al., 2000). Conversely, lambs supported by well-developed or highly efficient placentas during gestation frequently exhibit superior growth performance and attain higher slaughter weights within comparable production timelines.

The present findings suggest that Placental traits may serve as early-life indicators of long-term productive potential in lambs, thereby reinforcing the importance of prenatal development in shaping lifetime performance.

3.3. Interactions between Placental Traits, Birth Weight, and Postnatal Growth

The relationship between placental traits and postnatal growth is a multifactorial one, with birth weight serving as one of numerous mediating factors. Although a higher birth weight generally indicates a greater likelihood of favorable early growth outcomes, placental traits such as efficiency and cotyledon development have the potential to independently influence postnatal performance by shaping fetal organ development and metabolic capacity (Reynolds et al., 2023; Toschi and Baratta, 2021).

It is suggested by studies which compare lambs with similar birth weights but differing placental morphologies (Greenwood et al., 2000) that placental function during gestation contributes to qualitative differences in growth potential that are not captured by birth weight alone. The importance of integrating placental indicators with neonatal measurements when evaluating growth performance is therefore emphasized.

4. Integrative Perspective and Future Research Directions

A salient implication that emerges from an examination of Sections 2–4 is that the concepts of "placental size" and "placental function" should not be treated as interchangeable in the context of ovine species. Research that relies exclusively on placental weight may fail to consider functionally significant variations captured by

cotyledon-based traits (e.g., average cotyledon surface area, total cotyledon surface area) and placental efficiency indices, which may better reflect the realized capacity for maternofetal exchange (Vonnahme et al., 2003; Ozyurek and Turkyilmaz, 2020). Indeed, analysis of numerous scientific studies has demonstrated that the most informative interpretation often arises from trait combinations (placental weight + cotyledon number + cotyledon size/surface area + efficiency/activity indices) rather than from any single metric considered in isolation (Şen, 2021).

It is hereby proposed that an integrative conceptual model for ovine species be formulated, in which the function of the placenta arises from the interaction of structural, morphological, and functional components. In this study, the placental capacity is shown to be shaped by the number and size of placentomes. Furthermore, it is suggested by the research that proxies of total exchange surface area also have a part to play in shaping placental capacity. Concurrent variation in placentomes morphology is also demonstrated in this study to reflect alternative developmental strategies and adaptive remodeling processes. The existence of a robust body of evidence that lends support to this integrated perspective is especially evident in studies that have examined placentome morphology. In such studies, the presence of different placentome types (A–D) has been demonstrated to correlate with disparities in placentome size, vascular development, and the outcomes of fetal growth. The findings indicate that placental remodeling is an adaptive response to intrauterine conditions rather than a stochastic developmental variation. It is important to note that the incorporation of placentome-type information provides a functional context for interpreting variations in placental morphology. This is due to the fact that it captures changes in the proportion of maternal and fetal tissues present at the exchange interface. Such changes are not adequately reflected by placental mass alone. Consequently, the integration of placentome morphology with quantitative measures of placental efficiency and exchange surface area offers a more comprehensive understanding of placental function in sheep (Vonnahme et al., 2008; Ashley et al., 2023).

It is of secondary significance to emphasize the necessity of fortifying the evidence correlating placental traits to postnatal growth variability in ovine species. This objective can be accomplished through the deliberate implementation of a developmental programming framework. Systematic reviews and meta-analyses in ovine species indicate that conditions experienced prior to birth can exert a lasting influence on fetal growth and postnatal development, thereby substantiating the notion of "carry-over" effects from the intrauterine milieu to subsequent performances (Sartori et al., 2020). At the mechanistic level, syntheses with a broader focus on livestock emphasize the prenatal origins of postnatal variation in growth efficiency and carcass-related outcomes, thereby supporting the view that prenatal

development is not merely a transient phase, but a determinant of lifetime productivity (Vautier and Cadaret, 2022). It is imperative for future sheep research to advance beyond the confines of merely cross-sectional correlations, adopting instead methodologies that can unravel the underlying mechanisms by which placental traits exert their influence on postnatal growth. This exploration should encompass the direct impacts on fetal tissue development and metabolic capacity, as well as the indirect effects via birth weight and early survival selection.

The most pressing practical challenge is arguably methodological standardization. The existing literature utilizes a variety of definitions and measurement methods for cotyledon size and surface area (e.g., sampling strategies, the distinction between "average" and "total" cotyledon surface area, and the differentiation between small and large cotyledons) (Ozyurek and Turkyilmaz, 2020; Şen, 2021). This heterogeneity in definitions and measurement methods hinders the comparability of research findings across different breeds and studies (Ozyurek and Turkyilmaz, 2020; Şen, 2021). A primary objective for the field is to establish a minimum set of standards for the reporting of ovine placental studies (gestational timing, placental weight, cotyledon number, standardized surface area estimates, placentome morphology/typing where feasible and explicit litter size stratification). Furthermore, the enhancement of interpretability would prove advantageous in the context of breed-comparison endeavours that have recently commenced the classification of indigenous breeds on the basis of placental trait patterns through multivariate approaches (Şen, 2021).

A further pivotal prospective trajectory entails the more methodical integration of genotype and Placental Phenotype. The extant body of research indicates that both maternal and fetal genotypes can influence conceptus development and characteristics of the placentome. This lends support to the hypothesis that "placental strategy" has a genetic element that may be subject to variation among breeds or selection histories (Vonnahme, 2012). At the interface between endocrinology and molecular biology, reviews emphasize the pivotal function of insulin-like growth factors (IGFs) in regulating placental resource allocation to fetal growth. These IGFs provide a biologically coherent pathway through which genetic and environmental inputs may influence placental phenotype and, consequently, ultimately affect fetal growth outcomes (Sferruzzi-Perri et al., 2017). The integration of perspectives focused on the insulin-like growth factor (IGF) with those centered on pregnancy adaptations of the broader growth hormone-IGF axis may further elucidate the manner in which maternal endocrine dynamics interact with placental development (Kaur et al., 2025). While this review has deliberately given less emphasis to nutritional details, it is recommended that

future research continues to employ endocrine markers to help elucidate the reasons why placentas with similar morphological characteristics can result in different fetal and postnatal phenotypes.

From an observational standpoint, the implementation of several targeted approaches would serve to strengthen the evidence base in question. Firstly, it is imperative that studies routinely model placental traits-birth weight relationships with explicit term interaction for litter size and parity. This is due to the robust biological and empirical evidence that these factors modify placental development and fetal growth trajectories (Kaşıkçı et al., 2011; Vonnahme et al., 2003). Secondly, in order to ascertain the extent to which postnatal growth variance can be attributed to placental structure and efficiency, beyond birth weight alone, it is necessary to longitudinally follow-up lambs with well-characterised placental phenotypes. This is in accordance with the calls emerging from the developmental programming literature (Sartori et al., 2020). Thirdly, there is mounting evidence to suggest that more frequent adoption of placentome morphology assessment (A-D typing) could assist in resolving the observed inconsistencies by facilitating the identification of adaptive placental rearrangement patterns that are obscured when solely mass-based traits are observed (Vonnahme et al., 2008; Ashley et al., 2023).

In conclusion, the integration of the findings from Sections 2 to 4 indicates that the advancement of ovine placental research will be most expeditious in instances where there is alignment of three objectives: the establishment of a standardized phenotyping, the provision of a mechanistic anchoring, and the prediction of outcomes that are performance-relevant. It has been demonstrated that datasets with a focus on particular breeds, which incorporate comprehensive cotyledon metrics and calculated activity indices, illustrate the potential to convert placental structure into quantitative indicators of infant size. This concept is further elaborated in the works of Ozyurek and Turkyilmaz (2020) and Şen (2021). The following step in the research is the extension of the predictive logic to postnatal growth and efficiency endpoints by means of longitudinal designs. The objective of this is to effect a transformation of the placenta from a descriptive endpoint into a practical biological lens for the understanding and, if possible, anticipation of variations in performance of the lambs.

5. Limited Standardization of Placental Measurements

A significant limitation in the present literature is the absence of standardized methodologies for measuring placental traits in sheep. The definition, sampling, and reporting of placental weight, cotyledon number, cotyledon size, and surface area vary significantly across studies, thereby hindering the establishment of direct

comparisons between experiments (Vonnahme et al., 2003; Ozyurek and Turkyilmaz, 2020; Şen, 2021). For instance, the surface area of cotyledons is estimated using various methods, including diameter-based calculations, weight proxies, and selective samples of placentomes. Each of these approaches has different implications for biological interpretation.

The implementation of a uniform placental phenotyping protocol in future research endeavors would undoubtedly prove advantageous. A protocol of this nature should encompass the gestational timing of sampling, alongside meticulously defined cotyledon metrics and consistent reporting of litter size-adjusted values. The implementation of such a standardization procedure would significantly enhance the replicability and comparable analysis of placental studies in ovine subjects.

6. Recommendations for Advancing Placental Research in Sheep

Based on the evidence synthesized in this review, future placental research in sheep should prioritize the development of standardized protocols for the measurement and reporting of placental traits. Harmonization of methodologies would substantially improve comparability among studies and facilitate robust synthesis of findings across breeds, production systems, and experimental designs. In parallel, greater emphasis should be placed on integrative and multivariate analytical frameworks that consider multiple placental traits simultaneously, rather than relying on single-parameter associations, in order to better capture the complex and adaptive nature of placental function.

Longitudinal study designs represent another critical research priority. Tracking lambs from birth through later productive stages while incorporating detailed placental phenotyping would enable clearer assessment of the extent to which placental traits influence lifetime growth performance and efficiency beyond birth weight alone. Moreover, expanding placental research to include a wider range of sheep populations, particularly indigenous and locally adapted breeds, is essential for understanding genetic and adaptive diversity in placental development strategies that may be overlooked in studies focused on a limited number of commercial breeds.

Finally, future studies would benefit from closer integration of placental morphological data with endocrine and genetic information. Linking placental phenotypes with hormonal profiles and genotype-level variation may provide deeper mechanistic insight into the biological pathways governing fetal growth and postnatal performance. Together, these approaches will help advance placental research in sheep from largely descriptive associations toward predictive and mechanistically informed frameworks.

7. Conclusion

This review highlights the placenta as a central biological determinant of lamb birth weight and postnatal growth performance, extending its influence well beyond gestation. Evidence synthesized across studies consistently demonstrates that placental traits particularly placental weight, cotyledon number, cotyledon size and surface area, and indices of placental efficiency are closely associated with fetal growth outcomes and contribute to variability in early-life and longer-term performance in lambs (Reynolds and Redmer, 2001; Vonnahme et al., 2003). Importantly, placental mass alone does not adequately describe placental function, and reliance on single traits risks oversimplifying a highly adaptive and plastic organ.

An integrative interpretation of the literature indicates that placental function in sheep is best understood through the combined evaluation of structural capacity, morphological strategy, and functional efficiency. Cotyledon-based traits and placental efficiency indices frequently outperform placental weight alone in explaining variation in lamb birth weight, particularly when litter size, dam parity, and breed are considered (Ozyurek and Turkyilmaz, 2020; Şen, 2021; Ashley et al., 2023). These findings reinforce the concept that the ovine placenta can adopt alternative developmental strategies favoring either size or efficiency to support fetal growth under differing biological constraints.

Beyond birth, placental traits exert persistent effects on postnatal growth trajectories, supporting the framework of developmental programming in sheep. Lambs originating from placentas with limited functional capacity often exhibit altered growth patterns, including reduced early growth rates or reliance on compensatory growth, which may carry biological trade-offs affecting efficiency and carcass composition (Greenwood et al., 2000; Reynolds et al., 2023). Thus, placental development represents a foundational component of lifetime performance rather than a transient gestational phenomenon.

Despite substantial progress, the current body of literature is constrained by methodological heterogeneity, limited longitudinal designs, and inconsistent reporting of key placental traits. Addressing these gaps through standardized phenotyping, integrative trait analyses, and long-term follow-up studies will be essential for advancing understanding of how placental biology shapes productivity in sheep. Incorporating placental indicators into broader performance evaluations may ultimately improve interpretation of growth variability and provide a biologically grounded perspective for future research in small ruminant science.

In conclusion, recognizing the placenta as a dynamic and functionally diverse organ offers a unifying framework for linking prenatal development with neonatal outcomes and postnatal growth performance in lambs. Continued integrative research on placental traits will be critical for

refining our understanding of early-life determinants of productivity and resilience in sheep production system.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	D.T.	Ü.D.
C	50	50
D	50	50
S	50	50
DCP	50	50
DAI	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

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