Non-Destructive Methods for Analysing the Body and Carcass Composition of Sheep and Goats

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INTRODUCTION

Meat stands as a crucial protein source in the human diet. Concerns about the differences in production systems, feeding methods, and animal rearing practices are increasingly significant in today's society. Simultaneously, consumers are becoming more conscientious about the production processes, what they consume, and how their food is sourced. The farm-to-fork strategy, emphasizing transparency and sustainability, is now a prerequisite for all stakeholders in the food sector, aiming to create fair, healthy, and environmentally friendly food systems.

The assessment of body or carcass composition in various animal species has a rich history. It has been a persistent challenge for producers, meatpackers, retailers, and consumers across all zootechnical interests, with sheep and goats being no exception. Over time, diverse methodologies have been explored to obtain efficient tools for estimating elemental body composition. This information proves vital for genetic improvement, optimization of feeding plans, and commercial classification of carcasses, employing methods recognized by all players in the meat industry.

From traditional techniques like body palpation to cutting-edge technologies, the focus has always been on rapidly and effectively estimating animal composition or body condition. This is crucial for genetic improvement, carcass grading, evaluation, elemental composition estimation, and predicting meat quality. Metrics such as live weight, carcass weight, and body condition have been conventionally employed. Linear measurements gained popularity in the 1960s for evaluating animals and classifying carcasses in slaughterhouses.

In the realm of sheep and goats, methodologies have included subjective measurements like body condition scores, body and carcass weight, linear measurements, and indexes. The use of carcass composition joints, the number and size of adipocytes, dilution techniques, and under-water weighing have also been explored. Recent years have witnessed substantial advancements in non-destructive and non-invasive techniques, such as optical probes, video image analysis, total body electrical conductivity, bioimpedance analysis, ultrasounds, and various spectroscopy methods.

Despite differences in accuracy and applicability, these techniques have significantly contributed to body and carcass composition prediction. While proven successful in cattle and pigs, the effectiveness of these techniques in sheep and goats initially faced challenges. Factors such as thin subcutaneous fat, minimal differentiation between muscle and fat layers, the absence of subcutaneous fat in goat dorsal regions, and the presence of wool or long hair posed limitations to certain methods.

The upcoming book reviews recent technological strides in using non-destructive and non-invasive techniques to assess the body and carcass composition quality of sheep and goats. It delves into strategies for monitoring the production cycle, assessing meat compositions, and predicting body fat deposition, including intramuscular fat. Techniques such as ultrasound scanning, computer vision, dual-energy X-ray absorptiometry, computed tomography, magnetic resonance imaging, and bioelectrical impedance analysis are highlighted and discussed. These methods aim to provide comprehensive information on body and carcass traits throughout the stages of sheep and goat meat production.

LIVE WEIGHT AND BODY CONDITION SCORE

Live weight, referring to the weight of the animal's body at any given moment from birth, is a crucial metric providing insights into the dynamic changes occurring during growth. This information is indispensable for studies on animal growth and body composition. Live weight serves as a key variable in conjunction with other factors in prediction models, allowing for the assessment of body or carcass composition. It is also integral to quality carcass grading systems, aiding in the calculation of carcass yield.

While live weight is relatively easy to obtain, requiring only a scale, its accessibility may be limited under certain animal management conditions. Moreover, there remains a challenge in distinguishing true growth, representing the increase in cell mass (bone, muscle, and fat), from the weight attributed to food and water ingestion. Understanding the genuine growth of an animal is essential as it involves changes in shape and body composition. Since not all parts of an animal are edible or desirable, it becomes pertinent to explore the relationship between various body components, such as the yield of lean meat or strategies to reduce the proportion of fat in the carcass.

However, the differentiation between fat and muscle is not readily achievable through knowledge of live weight alone. In live animals, measuring and assessing total body reserves, especially those in the abdominal cavity, pose challenges without specific equipment and sophisticated technology. Therefore, obtaining a comprehensive understanding of the intricate interplay between fat and muscle necessitates advanced methodologies and tools, particularly for assessing internal reserves that significantly impact overall body composition. The study by Guerra et al. (1972) on the chemical fat proportion in live sheep bodies revealed that the condition score emerged as a superior predictor of fat levels compared to live weight. However, in instances where animals are of similar body size, the accuracy of predicting body fat becomes comparable between body weight and condition score.

Teixeira et al. (1989), focusing on Rasa Aragonesa breeds, found that Body Condition Score (BCS) was a more reliable predictor than live weight for both total body fat and individual fat depots, including subcutaneous, intermuscular, omental, mesenteric, kidney, and pelvic fat.

Russell et al. (1969) had previously demonstrated in Scottish Blackface ewes that body condition scores could offer a reliable estimate of fat proportion in live animals, surpassing the predictive capacity of live weight. The change in live weight per unit in condition score was found to be 11.3 kg, similar to the 10.56 kg reported by Russel et al. (1969) for Scottish Blackface ewes. This value was higher than the 5.8 kg found by Hossamo et al. (1986) in fat-tailed Awassi sheep and the 7.9 kg found by Kenyon et al. (2004) in Romney ewes.

A curvilinear regression analysis by Teixeira et al. (1989) showed that increases in live weight for a unit change in BCS ranged from 7 to 16 kg for each one-point increase in condition score from 1 to 5. Moreover, changes in the weight of fat depots per unit change in condition score indicated that intermuscular fat would be the first depot to be mobilized during a reduction in body condition from 2 to 1. Conversely, increases in condition score from 3 to 4 or from 4 to 5 would result in the greatest rate of fat deposition occurring in the subcutaneous and omental depots.

In a comprehensive review, Kenyon et al. (2014) highlighted that the relationship between live weight and body condition score may vary based on factors such as breed, sexes, ages, and physiological states at the time of measurement (dry, breeding, lactating). Despite potential variations, condition scoring proves more practical than live weight in many scenarios, as it can be conducted anywhere without the need for a cage scale. Additionally, condition scoring eliminates the need to correct for factors influencing live weight, such as body shape, gut content, wool weight, fetal weight in pregnant ewes, or fluid weight during lactation. So, there is a consensus that the fat and muscle reserves along the backbone can be assessed using the body condition score method. The visual assessment of body shapes and the palpation of body fat deposits have been ancestrally used by breeders, livestock handlers and butchers since the beginning of the domestication of sheep and goats. It was Alan Murray in 1919, in a remarkable scientific approach for the time, who defined the body condition as the ratio of the amount of fat to the amount of non-fatty matter in the body of the living animal, and the term "fattening" as any alteration in this ratio. Murray's approach was innovative, attempting to establish a scale of points that correlated body condition with the amount of chemical fat in body weight. Descriptive terms were used by Murray to indicate the increase or decrease of fat relative to non-fatty matter in order to create a scale that related to body condition in sheep. This historical perspective underscores the long-standing recognition of the importance of assessing body condition in sheep and goats and the efforts to develop systematic methods for quantifying and understanding the relationship between fat and non-fatty components in the body. The BCS method remains a valuable tool in the hands of those involved in the care, breeding, and management of these animals. For sheep he established the following relations:

Condition	Body fat (%)
Half fat	25.8
Fat	37.9
Very fat	48.3

but the relations between condition and body fat percentage used by practical experts would be interpreted approximately as:

Condition	Body fat (%)
Very lean	less than 5
Lean	from 5 to 10
Store	10 to 15
Fair (good store)	15 to 20
Half fat	20 to 25
Moderately fat	25 to 30
Fat	30 to 35
Prime	35 to 40
Very fat	40 to -

Jefferies (1961) in Australia made a significant contribution to the assessment of body condition in sheep by proposing a five-point scale. According to Jefferies, the lumbar region around the backbone, as well as the loin area on the spinous and transverse processes of lumbar vertebrae, was identified as the most appropriate regions for evaluating fat deposition in the body.

Jefferies introduced a score chart with six grades, where grade 0 corresponded to the point of death when sheep were highly emaciated due to prolonged drought or disease. This six-grade scale likely provided a comprehensive and nuanced assessment of body condition, allowing for a more detailed understanding of the range of conditions that sheep might experience.

The other scores specified were:

1. Poor Store Condition: This is a score that should not occur under good management.
2. Average Store Condition: It would suffice for wethers or adult dry sheep.
3. Forward Store Condition: a score for good condition for breeding ewes and young growing stock;
4. Fat: a condition score for ewes in late pregnancy and fat lambs to market.
5. Very Fat: an unhealthy and inefficient feed utilization that could quickly develop pregnancy toxaemia.

According to Jefferies (1961), the loin, being the latest developing part of the growing animal, is the last to accumulate fat and the first to lose it. As a result, Jefferies suggested that assessing the body condition status of sheep could be effectively done by palpating the backbone immediately behind the last rib and lumbar process with fingers (Figure 1). This method involves evaluating the prominence and sharpness of the backbone, feeling the amount of meat between the backbone and lumbar process, and assessing the thickness of the fat cover over the eye muscle, along with the thickness of the skin.

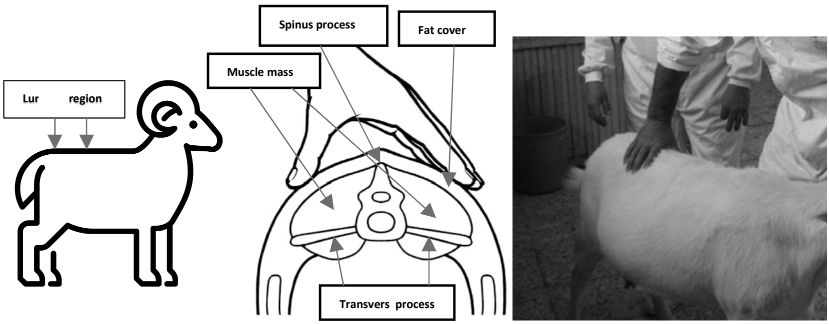

Figure 1. Body condition score assessment in sheep.

Feel the ends of the lumbar process and press the fingertips under the ends to assess the amount of meat (Figure 2). Feel them for sharpness and coverage of fat and meat. They assess the muscle area and feel it for thickness and fat coverage.

Figure 2. Feeling the ends of lumbar process in sheep.

The method proposed by Jefferies (1961) was later summarized by Russel et al. (1969) based on a 0 to 5 scale (Table 1) with a concept of 0.5 and 0.25 units and using a methodology based in four stages according to Figure 3 (Russel et al., 1984).

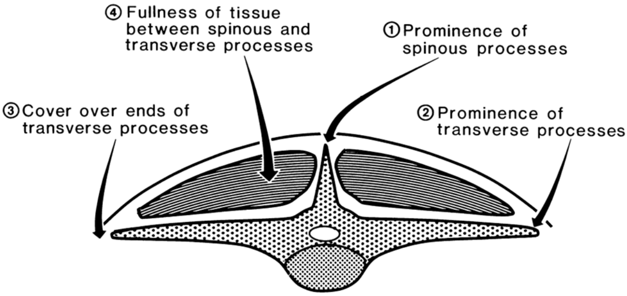

Figure 3. The four stages in the assessment of body condition score in lumbar region of sheep (Russel, 1984).

Table 1. Body condition scores description (Russel et al., 1969)

Grade	Description
0	Extremely emaciated and on the point of death.
1	Spinous processes are prominent and sharp; transverse processes are also sharp; the fingers pass quickly under the ends, making it possible to feel between each process. Mm. Longissimus dorsi shallow with virtually no subcutaneous fat cover
2	Spinous processes are prominent but smooth, and individual processes can be felt only as fine corrugations; transverse processes are smooth and rounded, and fingers can be passed under ends with slight pressure; Mm longissimus dorsi of moderate depth with little subcutaneous fat cover.

3	Spinous processes have a slight elevation, are smooth and rounded, and individual processes can be felt only with pressure; transverse processes are smooth and well covered, and firm pressure is required to feel over ends; Mm. Longissimus dorsi full with moderate subcutaneous fat cover.
4	Spinous processes can be detected with pressure as a hard line between ends; Mm. Longissimus and associated subcutaneous fat; transverse processes cannot be felt; Mm. Longissimus dorsi is covered with a thick subcutaneous fat cover.
5	Spinous processes cannot be felt even with firm pressure, and there is a depression in subcutaneous fat where spinous processes would usually be felt; transverse processes cannot be felt. Mm. Longissimus dorsi very complete with very thick subcutaneous fat cover; there may be large deposits of fat over the rump and tail.

Santucci (1984), inspired by the method proposed by Russell et al. (1969) and considering the incipient fat deposition in the lumbar region of goats, introduced a body condition scoring grid based on palpation of the sternum. This approach, presented during an FAO Seminar on Nutrition and Feeding of the Goat in Switzerland, prioritized the assessment of the sternum as it is an anatomical site with significant subcutaneous fat deposition.

In Santucci's proposed grid, the body condition score for goats is determined by palpating two regions, following a specific order of priority: first, the sternum, and then the lumbar vertebrae. The initial point of appreciation involves assessing the sternal fat, considering its thickness, width, and the thickness of the surrounding tissue layer covering the chondro-sternal joints. Subsequently, at the lumbar level, the degree of fat recovery of the vertebrae is evaluated using multiple points of reference, including transverse, spinous, and articular processes, as suggested by Russell.

The total score is derived from the assessment of these two sites, with the sternal evaluation being considered decisive. Santucci proposed a 5-point grid, where each grade is determined by the evaluation of the animal's overall appearance, sternal assessment, and lumbar evaluation. Each degree can be further specified with a + or - to fine-tune the appreciation of the two handling points, providing a more detailed and nuanced approach to assessing the body condition of goats.

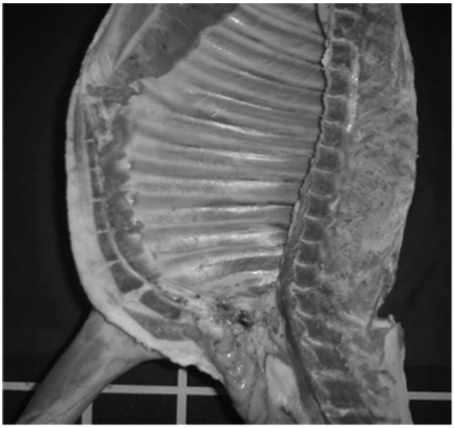

Figure 4. A goat carcass shows a lack of subcutaneous fat in the dorsal region compared to the sternal region.

During a meeting on the Body Condition of sheep and goats at the CIHEAM-IAMZ in Zaragoza, Spain, in 1990, Hervieu et al. (1991) established a five-point grading system for scoring the fat pad on the sternum that can be pinched. This approach aimed to provide a standardized method for assessing body condition in sheep and goats. Recognizing the challenges posed by varying circumstances, including species (sheep or goats), body size, and physiological and productive states, Teixeira et al. (1989) and Delfa et al. (1989) conducted studies to identify the most effective anatomical regions for assessing body condition. They proposed the palpation of the tissue around the tail in conjunction with the lumbar square joint, as defined in Figure 5.

This method involves evaluating specific anatomical regions—particularly the tissue around the tail and the lumbar square joint—to gain insights into the overall body condition of the animals. The combination of these palpation points allows for a more comprehensive and adaptable assessment, accommodating the variations in body size, species, and physiological state. These refinements in body condition scoring contribute to more accurate and relevant evaluations, enhancing the effectiveness of management practices for sheep and goats.

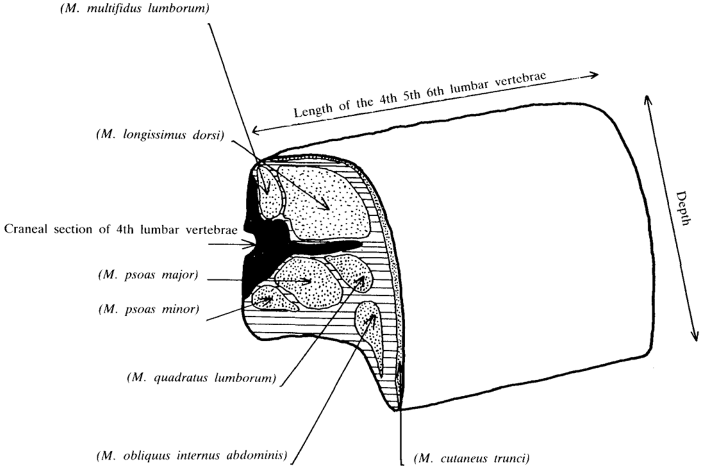

Figure 5. Lumbar square joint as the best region to assess the body condition in sheep (Delfa et al. 1989).

Delfa et al. (1995a), in their study with Blanca Celtiberica goats, focused on determining the relationships between various body fat depots and three distinct methods of assessing the condition score: sternal body condition score, lumbar body condition score, and tail body condition score. The findings of their research indicated that the score assessed in the sternal region was a superior predictor compared to the other body condition scoring methods. In particular, the sternal body condition score demonstrated greater accuracy in predicting all fat depots.

Recognizing the importance of understanding and monitoring an animal's body condition for effective food management and optimal herd productivity, coupled with the imperative for producers to acquire proficiency in assessing the body condition of their goats, the Langston University Goat Farm took proactive steps in 2008 during the Goat Field Day. Here, they devised a program aimed at instructing individuals on how to accurately score body condition in goats (Detweiler et al., 2008). Building upon the groundwork laid by the aforementioned authors, the program proposed evaluating specific anatomical regions, notably the sternal and lumbar areas. Additionally, the authors suggested incorporating assessment of the rib cage as another key point of evaluation. Accordingly, Detweiler et al. (2008) advocated for the evaluation of three distinct areas to assign a condition score: the lumbar region, housing the loin muscle; the sternum; and the rib cage (refer to Figures 6, 7, and 8).

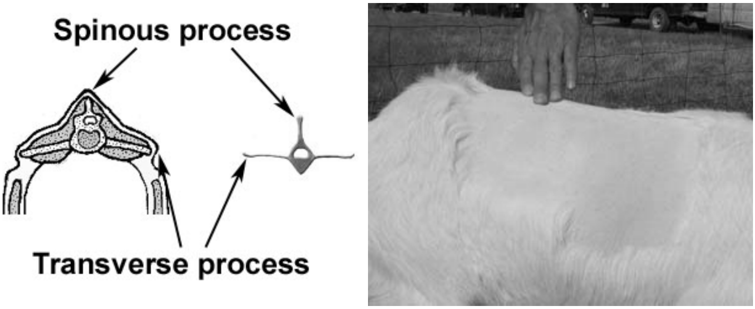

Figure 6. Scoring in the lumbar area, as in sheep, is based on determining the amount of muscle and fat covered over the vertebrae, feeling with the fingertips the sharpness of the spinous and transverse processes of the lumbar vertebrae.

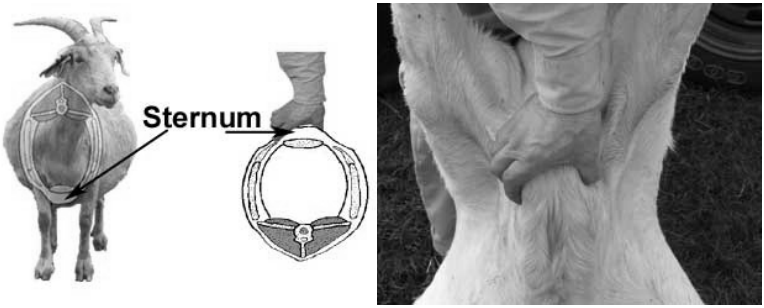

Figure 7. Feeling the fat layer covering the sternum and scoring this area according to the thickness of the fat pad on the breastbone can be pinched.

Figure 8. Assessing the fat cover over the ribs.

Sheep scoring is performed in goats using a condition score ranging from 1.0 to 5.0, with 0.5 increments. A condition score of 1.0 is a skinny goat with no fat reserves, and a BCS of 5.0 is a very over-conditioned (obese) goat. Healthy goats should have a BCS of around 2.5 to 3.0. Scores below 2.0 indicate a management or health problem, and scores above four are rarely observed in goats under typical management conditions. However, these scores can sometimes be observed in show goats (Detweiler et al., 2008). Hervieu et al. (1991), according to the fat cover and muscle depth of the goat lumbar region, pointed out a precise description of a 5-point scale to assess body condition, as shown in Figure 9. However, as already mentioned, the fat cover of the dorsal region of goats is not appreciable in the sternum region. It has been proposed as the most suitable for assessing the body condition of goats, where a large amount of fat is visible, providing a more accurate assessment.

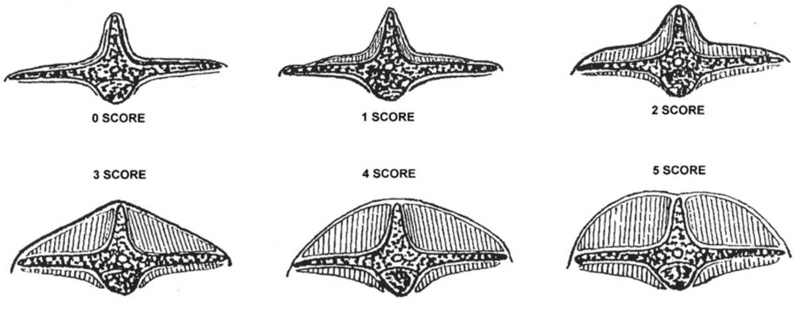

Figure 9. Goat body condition score in lumbar region (Hervieu et al., 1991)

In this sense, a 5-point scale was defined for the sternal region (Figure 10) with a description of the amount of fat and tissue thickness that should be used in addition to the grade assigned in the lumbar region.

The subjective nature of the body condition assessment method requires training evaluators. In the early 1970s, the UK Ministry of Agriculture, Fisheries and Food defined the condition scoring as a system depending on the description of specific physical characteristics identifiable in sheep of different degrees of fatness and assessed on and around the backbone in the loin area immediately behind the last rib and above the kidneys. The Central Veterinary Laboratory developed plastic models with different patterns of the body condition scores simulating the different fat deposition and muscle depth for training the different degrees of prominence of the spinous and transverse processes and the thickness of muscle. These models, reproduced in Figure 11, were kindly sent to R. Delfa and A. Teixeira by Dr B. Dumont from INRA by Jooy-Josas France for their usage at the end of '80s at CITA in Aragon, Zaragoza - Spain.

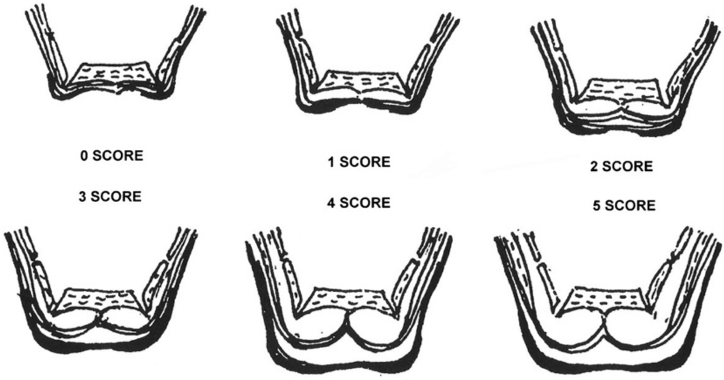

Figure 10. Goat body condition score in sternum (Hervieu et al., 1991)

Figure 11. Plastic models with different patterns of body condition score 1 to 5.

Even so, the repeatability between and within the evaluators of the scores assigned can be a significant constraint in the method's efficiency. The difficulty of assessing body condition derived from the subjectivity of the method used was addressed by Everitt (1962). Using a scoring system of 10 points where 10 = very fat and 1 = emaciated. Everitt found that assessment of "condition" (fat) in Merino sheep showed considerable variation in judgment both within and between five individual observers and concluded that body fat content could not be accurately predicted from a "condition" score or live weight. Later on, Milligan and Broadbent (1974), in a study with Romney March ewes, examined the repeatability of 3 operators assessing body condition three times and found a moderate repeatability (0.49 - 0.67) and concluded the technique would require initial learning and subsequent recalibration before using with precision by farmers. Also, Yates and Gleeson (1975) working with inexperienced operators, assessing the body condition in Merino, ewes found low repeatability within (0.19 – 0.44) and between operators (0.55 – 0.27). Evans (1978) conducted experiments to evaluate the method's accuracy in real-world conditions. The tests yielded a repeatability value of 0.88 and a reproducibility value of 0.81. The results indicated the significance of training assessors carefully and conducting standardization exercises regularly. Experienced assessors achieved values with significant levels of repeatability accuracy of 80% and 90% of reproducibility, even scoring ewes to 0.25 score units (Teixeira et al., 1989). Values close to these were also obtained later by Shands et al. (2009) comparing manual assessment of ewe fat reserves for on-farm use, van Burgel et al. (2011) training the conditions score as an alternative to live weight for managing the nutrition of ewes and Phythian et al. (2012) studying the reliability of body condition of sheep for cross-farm assessments.

The purpose of assessing and scoring the body condition of sheep was initially stated by Jefferies (1961) to consistently and accurately use the method in management:

(1) to detect small changes in body condition not noticeable by outside appearance
(2) to be immediately aware of significant losses in body condition as a result of bad food quality or diseases
(3) to follow trends in nutrition and body weight of young sheep and those with special food needs
(4) to control the condition and the more efficient use of food supplies.

The Montana State University designed a Sheep Ration Program to help producers meet the nutritional needs of their sheep and suggested the following condition scores for the various stages of the production cycle:

Production stage	**Optimum score**
Breeding	3 - 4
Early Mid Gestation	2.5 - 4
Lambing (singles)	3.0 – 3.5
(twins)	3.5 - 4
Weaning	2 or higher

(Thompson and Meyer, 1975)

The method was used to monitor management operations in sheep, mainly its relationship with reproductive traits such as ovulation rate, conception rate, fertility, prolificacy, and other traits. Kenyon et al. (2014) reviewed the sheep body condition and its relationships with production characteristics. Since Murray's study, in which the first relationship was made between body condition and body composition, only some studies have been conducted on sheep and even fewer on goats (Table 2).

Table 2. Summary of studies of the relationship between body condition score and body composition on sheep and goats

Reference	Specie	Method	Body composition	R	RSD
Russel et al. (1969)	Sheep	BCS	% Chemical fat	0.94	n.a.
Guerra et al. (1972)	Sheep	BCS	% Chemical fat	0.77	n.a.
Yates, Gleeson (1975)	Sheep	BCS	% fat + muscle	0.72 – 0.61	n.a.
Teixeira et al. (1989)	Sheep	BCS	Fat depots weight	0.84 – 0.95	0.12 – 0.20
McGregor (1992)	Goats	BCS	Subcutaneous, body fat	0.77 – 0.87	0.71 – 1.16
Sanson et al (1993)	Sheep	BCS	% Lipid	0.90 – 0.95	0.35
Treacher and Filo (1995)	Sheep	BCS	Fat depots weight	0.23 – 0.67	0.36 – 0.44
Delfa et al. (1995a)	Goats	Sternum BCS Tail BCS	Fat depots weight	0.87 – 0.94 0.87 – 0.92 0.83 – 0.86	0.93 – 0.96 0.93 - 0.96 0.90 - 0.93
Frutos et al. (1997)	Sheep	BCS	Fat depots weight	0.33 - 0.54	218 - 997
Mendizabal et al. (2003)	Sheep	BCS	Fat depots weight	0.55 – 0.77	0.55 - 0.85

n.a. not available

The body condition method regardless of whether the lumbar region, sternal region, or tail palpation was used in the different studies carried out in sheep and goats, showed different degrees of accuracy of the different regression equations used as the leading prediction model. Two models of ultrasound devices are used. However, the use of the method does not require any special equipment; we must always pay attention to its subjectivity, the need for training of assessors, and the type of prediction models used, which will only be reproducible under identical experimental conditions. in which they were tested, mainly species, sex, physiological status and production cycles.

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MORPHOLOGICAL MEASUREMENTS

Body dimensions, often alone or associated with live weight or body condition score, are the most helpful and cheapest methods to predict in vivo body composition. The method uses biometric measurement instruments to measure lengths, heights and perimeters through defined anatomical points to relate these measurements to body composition. Figures 12 and 13 show some of the most usual measurements taken in goats and sheep, respectively.

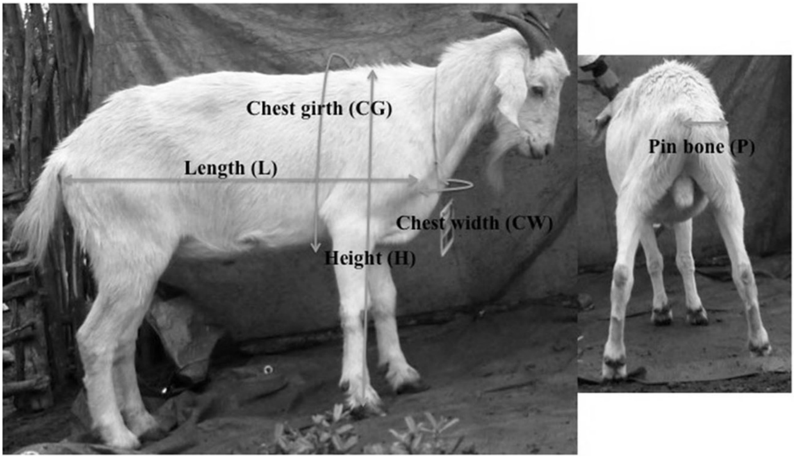

Figure 12. Morphological measurements in goats. The body measurements included chest girth (CG), chest width (CW), height (H), length (L), and pin bone (PB). (Mdladla et al., 2017)

The first studies, mainly carried out in cattle, were promising, with high correlations between external body measurements and tissue weight, particularly the bone, obtained within groups of animals with a wide variation in size and shape. However, accurate measurements of soft tissues such as muscle and fat were more challenging. Also, Kempster et al. (1982) refer to concerns that the accuracy could be better to discriminate between members of relatively homogenous groups of animals and low susceptibilities of some measurements to estimate soft tissues. In cattle, body dimensions were widely used to predict body composition in vivo in sheep and goats; some studies are summarized in Table 3.

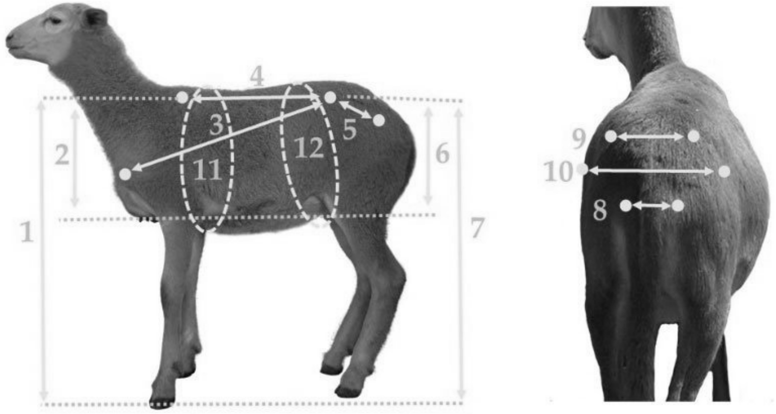

Figure 13. Morphological measurements in sheep. (1) height at withers, (2) rib depth, (3) body diagonal length, (4) body length, (5) pelvic girdle length, (6) rump depth, (7) rump height, (8) pin bone width, (9) hook bone width, (10) abdomen circumference. The body measurements included chest girth (CG), chest width (CW), height (H), length (L), and pin bone (PB). (Bautista-Diaz et al., 2020)

Table 3. Summary of studies of the relationship between body dimensions and body composition on sheep

Reference	Specie	Prediction	Variables	RSD	R
Agamy et al. (2015)	Sheep; Fat-Tailed breeds	Trimmed meat (kg) Trimmed meat (kg) Bone (kg) Bone (kg)	HG HG + BL HG + BL HG + BL + HW	0.11- 0.15 0.07 0.02 0.02	0.66 – 0.89 0.72 0.61 0.69
Bautista-Díaz et al. (2017)	Sheep; Pelybuey	Carcass fat (kg) Bone (kg) Body fat (kg)	HW + AC + PGL RuD + RH AC + HBW	0.83 0.26 2.52	0.93 0.67 0.81
Bautista-Díaz et al. (2020)	Sheep; Hair	Fat + muscle (kg) Bone (kg)	SBW + RuD + AC SBW + RD + GC	0.33 0.10	0.91 0.86

Gomes et al. (2021)	Sheep; Santa Inês	Muscle (kg) Fat (kg) Bone (kg)	BW + ChW + BCI SBW1 + WH SBW1	0.17 0.04 0.05	0.91 0.84 0.81
Barcelos et al. (2021)	Sheep Hair	Fat (%) Protein (5)	ThorC+HindC+ChestW Hind C + ThorC + ChestW	2.71 0.95	0.56 0.79

All measurements were expressed in cm. HG – heart girth; BL – body length; HW height at withers; HW – height at withers; AC – abdomen circumference; PGL – pelvic girdle length; RuD – rump depth; RH – rump height; HBW – hook bone width; SBW – shrunk body weight; RD – rib depth; GC – girth circumference; SBW1- slaughter body weight; Chw – chest width; BCI – body compactness index; wh – wither height; ThorC – thoracic circumference; HindC – hind circumference; ChestW – chest width.

Although the studies carried out in sheep are recent, they denote flaws in the estimation models used, which can only be applied under the same management conditions in which they were calculated, that is, for these animals of these breeds in that period of life, weight and food systems. It should be noted that the models make estimates in kg of tissues with modest accuracy. There needs to be more objective information on how well body dimensions predict sheep and goat body composition, mainly comparing with more commonly used methods such as ultrasounds or other image analysis techniques.

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ULTRASOUND SCANNING

Leonardo da Vinci is credited with identifying the existence of sound propagated in an aquatic environment for the first time in 1490. However, the initial evidence of sounds not audible to humans can be attributed to Lazzaro Spallanzani (1729-1799), an Italian biologist, and Catholic priest. Spallanzani made a groundbreaking observation of bats using a navigation system to capture insects. Although his findings were not experimentally proven until the late 1930s, it was confirmed that several species utilize this navigation system, now defined as echolocation (Pierce & Griffin, 1938).

Echolocation, as a phenomenon, is associated with the piezoelectric effect of crystals, a discovery made by Jacques and Pierre Curie in 1880. This pivotal understanding paved the way for the development of the first transducers capable of generating and detecting ultrasonic waves. Today's modern ultrasound transducers and probes incorporate arrays of piezoelectric crystals, leveraging their vibrational properties to generate and receive sound waves. This fundamental principle forms the basis of contemporary ultrasound technology.

An ultrasound is a sound wave with a frequency higher than the audible range for humans, typically exceeding 20 kHz (20,000 cycles per second). These waves propagate through compression and exhibit properties such as reflection and refraction when passing from one medium to another. It's important to note that sound waves do not propagate in a vacuum, and their transmission through gases is relatively low. Ultrasound devices commonly operate within the frequency range of 20 kHz to 10 MHz. These devices typically consist of essential components, including a signal generator equipped with an amplifier, a transducer, and a monitor (Figure 14).

The ultrasonic generator converts the electrical energy into an ultrasound via the transducer containing crystals with piezoelectrical properties. The ultrasound transmitter is pulsed to allow time for reflected ultrasound to travel back to the transducer. Sound reflection is produced between interfaces with different acoustic impedances, such as the interface between muscle and fat. It is defined as the product between the sound's velocity and the medium's density crossed. The time elapsed between transmission and

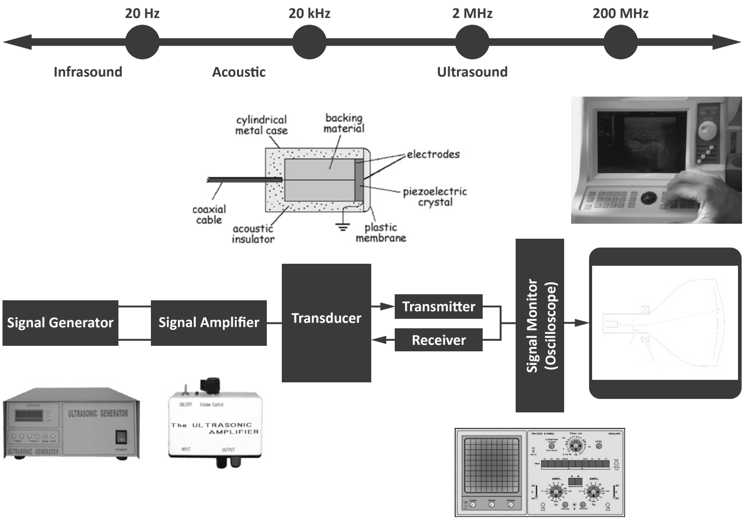

Figure 14. Acoustic spectrum and components of ultrasound equipment. (Teixeira, 2015)

reflection depends on the impedance of the interfaces of different tissues traversed by the ultrasound. The same or another crystal on the transducer generates ultrasound pulses and the reception of echoes. The echoes received can produce an image in the monitor of the scanner, which is related to the acoustic impedance of the tissues crossed by ultrasound waves and the ratio between the depth and the distance of its interfaces. Two types of ultrasound devices are used: the A-mode and B-mode or real-time machines. The A-mode method of measuring the amplitude of the echo in the function of time is now obsolete in image analysis. Real-time ultrasonography (RTU) is a version of B-mode measuring of the echo intensity in a two-dimensional scan, showing all the tissues screened by the ultrasound beam and creating several images that can be seen instantaneously by moving and changing the position of the transducer.

Contrarily to other technological advances, before researchers recognised the potential of ultrasounds in animal science, the first application of real-time ultrasound technology was in humans for medical reasons. The technology was developed to quickly observe the internal physiological movements of human organs, tissues, or fluids. However, it was first used to scan livestock by Horst in 1971, even though Stouffer et al. had already