

# Use of X-ray Computed Tomography to Estimate Sheep, Goat and Beef Carcass Composition – Preliminary Results

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**Abstract.** Greek ruminant meat production is challenged by the lack of objective carcass and meat evaluation protocols. X-ray Computed tomography (CT) is used as an innovative tool for carcass evaluation in many farm animal species. For the first time in Greece, in 2 beef, 13 sheep and 6 goat carcasses CT scans were performed to estimate carcass traits and composition. Image analysis protocols, formerly implemented in other species, were used to estimate carcass length and width as well as fat, muscle and bone volumes and weights. Our preliminary results indicate that accurate carcass composition estimations might be possible with the use of CT and image analysis. Results should be re-evaluated on a bigger sample size. Concurrent carcass dissections could facilitate the validation of CT estimations. Standardization of carcass composition evaluation protocols based on non-destructive methods can certify meat quality and contribute to the overall competitiveness and sustainability of the sector.

**Keywords:** X-ray Computed Tomography; ruminant carcass; lean meat yield; fat yield; bone yield

## 1 Introduction

Ruminant meat production in Greece represents 57.28% of non-poultry meat production. In 2018, Greek beef, sheep and goat annual meat productions were 39.65, 50.57 and 19.56 thousand tons, respectively (Ministry of Rural Development and Food, 2018). Only 30% of annual meat consumption is covered by domestic production. Beef meat is mainly based on purebred or crossbred male beef cattle that are slaughtered around the age of 24 months. Small ruminant meat production is a secondary activity of dairy production and mostly very young or old animals are slaughtered; no special diet is fed prior to slaughtering. Lack of objective carcass

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evaluation protocols has led to dramatic decreases in meat price. Carcasses are usually sold as whole or split in halves, a tradition which removed lamb and goat meat from modern household routine and made it a seasonal delight. New tools are necessary to evaluate carcass and meat quality and increase the competitiveness of the sector. Herein, we explore X-ray Computed Tomography (CT) as an innovative approach towards ruminant carcass quality evaluation.

So far, CT implementation on sheep aimed to predict carcass composition on live animals mostly for breeding purposes. Cross-sectional scans at three to seven specific anatomical positions were performed; non-carcass tissues were segmented semi-automatically with a specially designed image analysis software (Lambe et al., 2003; Karamichou et al., 2006; MacFarlane et al., 2006; Clelland et al., 2014). The 'reference' scanning method, as it is known, is widely used for commercial purposes because it is fast, accurate ( $R^2$  values ranging: 83-98.6%) and preserves animal welfare. Prediction equations used are breed-specific; hence, more inclusive approaches are needed (Navajas et al., 2006). Cavalieri method is an alternative which uses more cross-sectional images and utilizes inter-scan distances and tissue densities to estimate tissue volumes and weights. It is equally accurate and applicable across breeds, but more time-consuming (Bünger et al., 2011). Variations of the above are used in recent studies as standard methods for *in vivo* (Matika et al., 2016) or post-mortem carcass composition evaluations (Anderson et al., 2015; 2016). Respective applications of CT in dairy goats have been reported since the 1990's (Sørensen, 1992; Németh et al., 2010; Eknæs et al., 2017).

An approach based on spiral CT scanning of primal cuts and image analysis with special software has been used to estimate beef carcass composition (Navajas et al., 2010a). Accurate predictions of carcass tissue weights have been reported ( $R^2 = 0.89-0.97\%$ ). Large size of beef carcasses complicates CT scanning procedures and increases relevant costs. Thus, recent studies focus on CT scanning of specific muscles or carcass parts and investigate for possible correlations, which will allow predictions of total carcass composition (Navajas et al., 2010b; Anderson et al., 2018).

In another approach implemented on pigs, spiral CT scans are obtained from half carcasses or specific commercial cuts and image analysis software is used to separate tissues. To estimate tissue volumes and weights, voxel dimensions and tissue densities are utilized; results are highly accurate (Daumas and Monziols, 2011). This method can be implemented in a broad spectrum, since it was developed independently of dissection (Daumas and Monziols, 2016).

Considering the strengths and weaknesses of the above methods and the peculiarities of Greek ruminant meat production, the present study is a preliminary approach of CT as a post-mortem carcass evaluation tool in Greece.

## 2 Objective

The objective was twofold; (i) to use CT and image analysis protocols designed for carcass evaluation in other species (ie. pigs), to estimate sheep, goat and beef carcass traits (length, width) and composition parameters (volume and weight of muscle, fat

and bone tissues) and (ii) to compare the estimated sheep carcass quality parameters with respective dissection data of a previous study.

### 3 Materials and Methods

#### 3.1 Animals and Experimental Design

Dairy sheep and goats (mostly fat-tailed Chios sheep or other crossbreds) of both sexes at different live weights (representing 25%, 35%, 50%, 70% and 100% of mature weight –Table 1) were selected. Male, crossbred beef cattle at the optimum finishing weight were also selected. Animals were slaughtered in three commercial slaughterhouses. Sheep and goat carcasses were chilled for 24 hours then transferred to the CT scanner located at the Laboratory of Diagnostic Imaging, School of Veterinary Medicine, Aristotle University of Thessaloniki. Chilled beef carcasses were scanned 48 hours after slaughtering. In total, 13 sheep, 6 goat and 2 beef carcasses were scanned.

**Table 1.** Weight range per species in each of the live weight categories

		Weight range (kg)	
Live weight categories (% of adult weight)		Sheep	Goats
	25%	< 17.5	< 17
	35%	17.6 - 27.5	17.1 - 23.5
	50%	27.6 - 39.5	23.6 - 32.5
	70%	39.6 - 55	32.6 - 42.5
	100%	> 55.1	> 42.6

#### 3.2 X-ray Computed Tomography

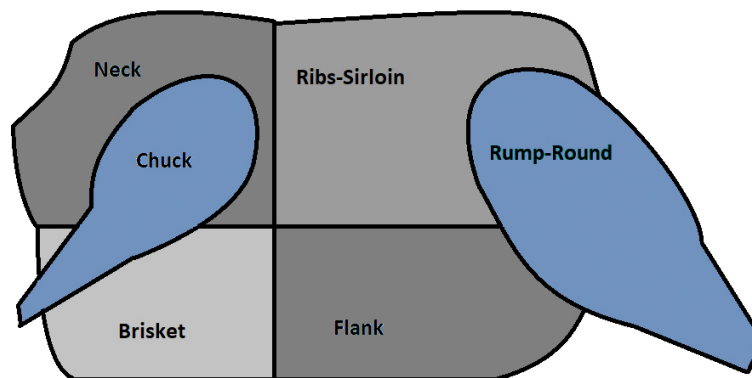
Beef carcasses were split in halves and one half was scanned. Beef carcass halves were dissected into six primal cuts (Figure 1) to facilitate the scanning procedure. Sheep and goat carcasses were scanned intact and contained remaining organs (heart, lungs, liver, internal fat, kidneys), except for heavier carcasses (70% and 100% of mature weight). The latter were longer than the maximum scanning length (110 cm); thus, two scans were performed representing front and back halves of carcasses. A helical volume of data comprising the carcass was acquired at 150 mAs and 120 kV, acquisition matrix 512x512 and convolution kernel STANDARD (soft tissues) using a 16-row multi-detector CT scanner (Optima CT520, GE Hangwei Medical Systems, Beijing China) (Figure 2). Transverse overlapping slices of carcass were obtained.

Slice thickness for small ruminants was 0.625 mm and ranged from 0.625 to 3.75 mm for beef. Field of view (FoV) ranged depending on carcass width, as did tube current since dose efficiency parameter (Optidose) was active (Table 2).

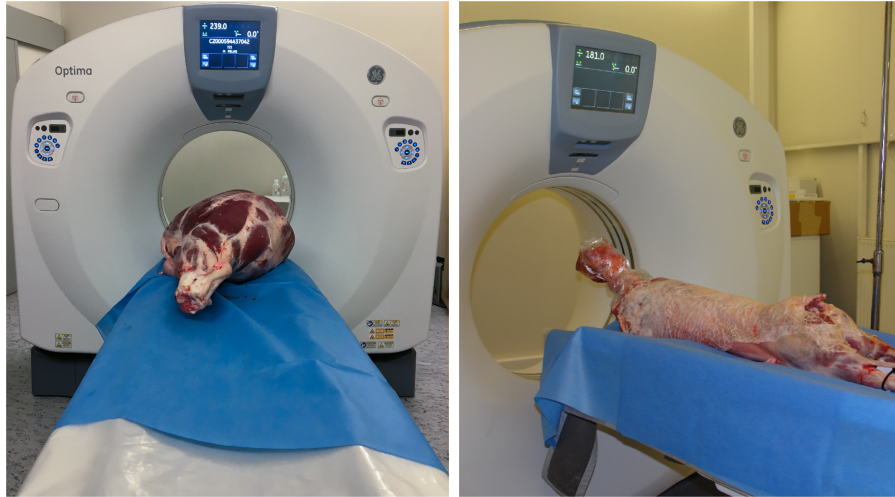
**Table 2.** CT Acquisition parameters per species

**CT Acquisition Parameters (per species)**

	<b>Sheep</b>	<b>Goats</b>	<b>Beef</b>
<b>FoV range</b>	246*246 - 454*454	228*228 - 440*440	389*389 - 500*500
<b>Tube current range (mA)</b>	49-345	49-349	49-350
<b>Tube tension (kV)</b>	120	120	120
<b>Acquisition matrix</b>	512 x 512	512 x 512	512 x 512
<b>Slice thickness (mm)</b>	0.625	0.625	0.625 – 3.75
<b>Convolution Kernel</b>	STANDARD (soft tissues)	STANDARD (soft tissues)	STANDARD (soft tissues)
<b>Type of scanning</b>	Spiral	Spiral	Spiral
<b>Dose efficiency (Optidose)</b>	Active	Active	Active



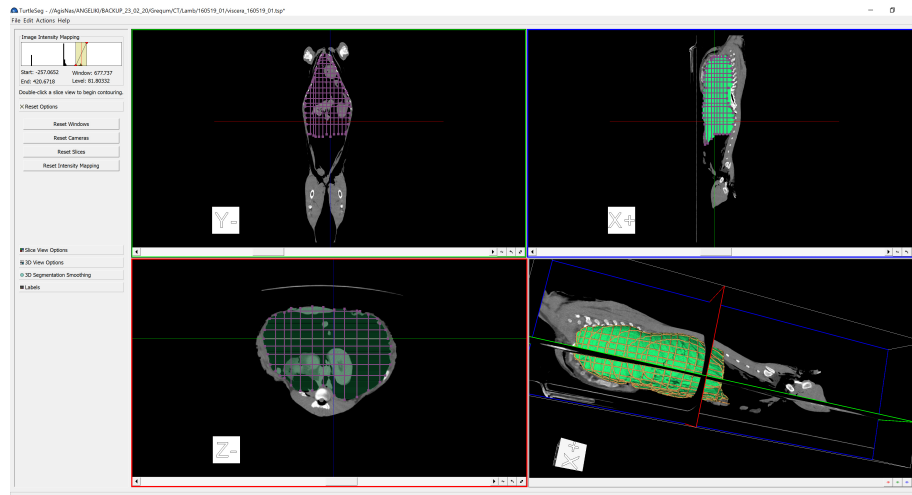
**Fig. 1:** Beef carcass primal cuts: (1) Neck, (2) Chuck, (3) Brisket, (4) Ribs-Sirloin, (5) Flank, (6) Rump-Round



**Fig. 2:** Beef round (left) and sheep carcass (right) undergoing CT scanning

### 3.3 Image Analysis

Remaining organs segmentation was performed using TurtleSeg software (version 1.2.1). To eliminate differences due to operator effect, only one trained researcher performed the protocol. Viscera area was selected by semi-manual contouring in several images (Figure 3); after completion, a 3-dimensional grid containing all viscera was created and exported as a new set of images, which was used to subtract these organs from the original dataset.



**Fig. 3:** CT images showing viscera segmentation with TurtleSeg software. In the right lower quartile, a 3-dimensional grid containing all viscera is depicted.

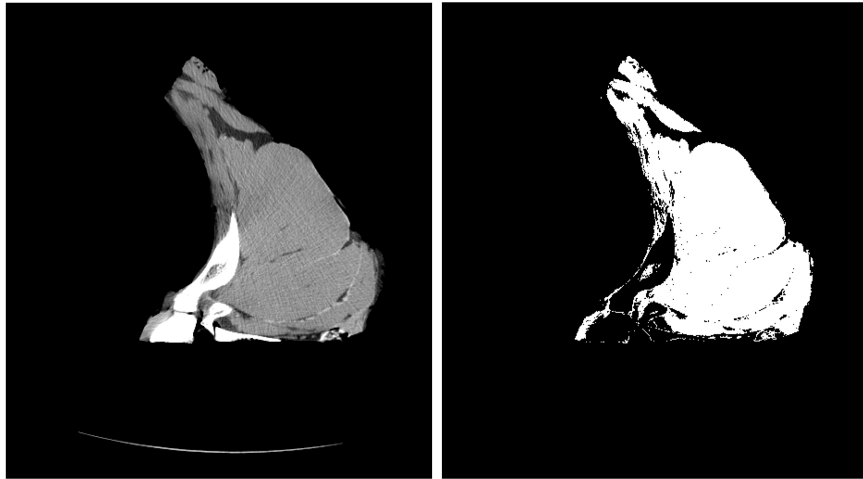
Image analysis was performed using ImageJ software (version 1.52t). By implementing density thresholds, image voxels were distributed to fat, muscle or bone tissue. Voxels in the Hounsfield unit (HU) range of 0 to 120 were considered parts of muscle (Figure 4). Voxels with density lower than 0 and those with higher than 120 were allocated to fat and bone tissue, respectively. Total number of tissue voxels multiplied by voxel volume (FoV/Acquisition matrix \* slice thickness) was used to calculate tissue volumes (Daumas and Monziols, 2011). Tissue weights were obtained by multiplication of tissue volumes by tissue densities (muscle: 1.04, fat: 0.95 – White et al., 1989; 1992). Due to differences in bone density, beef bone weight was calculated as the difference between carcass weight and fat and muscle weight. As most small ruminant carcasses included viscera, bone weight was not estimated.

Carcass width was measured on the 13<sup>th</sup> rib image of all carcasses (Figure 5). For carcass length measurement, the total number of consecutive images from the first depiction of the humeri bones until the first image of the femoral heads was multiplied by slice thickness.

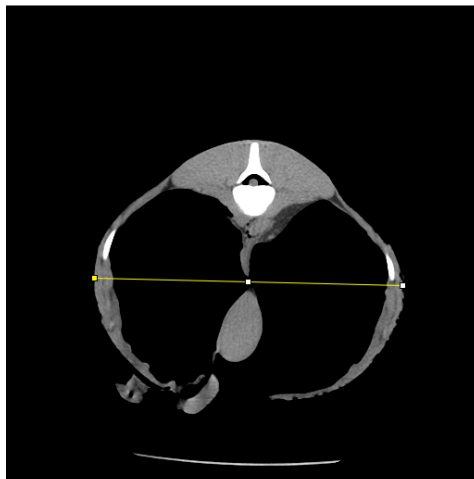
### 3.4 Historic Dissection Data and Analysis

Sheep carcass dissection data (muscle and fat weight) of an earlier study (Arsenos, 1997) were compared to the results of the present study. A total of 82 animals of both sexes and different live weights (13.9 – 71.6 kg) were used. Carcasses were split in halves and one half was fully dissected into muscle, fat and bone tissues, which were weighted following dissection. To optimize comparison, carcasses of the earlier study were grouped based on carcass weight to correspond to the weight categories of the

present study. Means of muscle and fat weight were calculated for each weight category in each dataset.



**Fig. 4:** Transverse CT raw image of beef ribs (left) and the same image after implementation of threshold for muscle (right) – ImageJ software



**Fig. 5.** Tranverse CT image at the level of the 13th rib of a sheep carcass, showing the carcass width measurement – ImageJ software

## 4 Results and Discussion

### 4.1 CT Carcass Traits and Composition Parameters

Means of carcass traits and composition parameters for each live weight category per species are presented in Tables 3a and 3b. Total number of carcasses differs in each weight category and in some cases no carcasses have been examined so far. As the study is still ongoing, results presented here are preliminary. Completion of the experiment will provide a larger sample of carcasses equally distributed in each live weight categories within species.

Estimated carcass length and width were in the normal range for each species. The method was fast and easily applicable; it is a good alternative to manual measurements.

As discussed in the introduction, CT scanning of sheep has so far been implemented in variable experimental protocols and on live animals. The latter complicate a direct comparison of results. Anderson et al. (2015), used a similar approach on a large sample ( $n=1665$ ) of Merino sheep (mean carcass weight: 23.3 kg); mean fat and muscle percentage were 27.0% and 57.1% of carcass weight, respectively. In the present study, the respective values were 16.7% and 40.5%. The difference may be due to variations between populations and samples; herein, a very limited sample ( $n=13$ ) of dairy sheep carcasses was used and mean carcass weighted only 16.9 kg.

Studies on goats are limited and close to sheep ones regarding methods (Sørensen, 1992; Németh et al., 2010). In a recent study (Eknæs et al. 2017), adult lactating dairy goats (mean live weight: 55.1-55.7 kg) were CT-scanned multiple times throughout lactation and the reported mean fat and muscle weights ranged between 7.5-11.4 and 14.2-14.8 kg, respectively. Herein, one adult male goat carcass (carcass weight: 32.6 kg, live weight: 73.0 kg) was examined, and the respective values were 4.8 and 16.3 kg. Variations in experimental protocols between studies and physical differences regarding tissue distribution and body weight between sexes might be causing the observed discrepancies.

Two beef carcasses (mean carcass weight: 389.9 kg) were examined and mean fat, muscle and bone percentages estimated were 12.0, 70.1 and 17.9%, respectively. Navajas et al. (2010a) followed a similar protocol for a bigger sample ( $n=44$ , mean carcass weight: 356.5 kg) and estimated mean fat, muscle and bone percentage of 20.4, 64.1 and 15.4%. Except for fat percentage, the other estimations are quite similar considering the differences between the two datasets.

The present results compared to other studies, demonstrate a tendency towards lower estimated fat and fluctuating muscle weights. Variable experimental designs and population parameters among studies complicate safe assumptions. Lack of dissection data directly related to the present dataset does not allow the proper validation of results.



**Table 3a.** Means of CT carcass traits for each live weight category per species

<b>Carcass Traits</b>						
	<b>total carcasses</b>	<b>male</b>	<b>female</b>	<b>carcass weight (g)</b>	<b>carcass length (mm)</b>	<b>carcass width (mm)</b>
<b>sheep 25%</b>	3	2	1	10666.67	551.04	154.13
<b>sheep 35%</b>	4	3	1	14200.00	586.75	159.78
<b>sheep 50%</b>	3	3	0	18133.33	666.67	164.75
<b>sheep 100%</b>	2	0	2	31200.00	836.88	329.24
<b>sheep total</b>	13	9	4	16907.69	635.43	185.69
<b>goats 25%</b>	4	2	2	8050.00	515.94	125.90
<b>goats 70%</b>	1	0	1	21600.00	822.50	218.88
<b>goats 100%</b>	1	1	0	32600.00	864.38	288.75
<b>goats total</b>	6	3	3	14400.00	625.10	168.54
<b>beef</b>	2	2	0	389900.00	1507.5	568.92

#### 4.2 CT and Dissection Data Comparison

Means of fat and muscle weight of dissected sheep carcasses are presented in Table 4. Mean carcass weights for each live weight category are similar between the two datasets; percentage change of mean CT-estimated values compared to dissection data varied from 1.71 to 4.53% by absolute value. Regarding fat weight means, slight differences were observed (percentage change: 3.24 – 6.23% by absolute value), except for light carcasses (25% of adult weight). Muscle weight means were slightly different for middleweight categories (35 and 50% of adult weight – percentage change: 3.96 – 7.74% by absolute value). In contrast, percentage changes were larger for heavier and lighter sheep (10.92 – 17.68% by absolute value). Generally, CT-estimated muscle and fat weights were close to dissection data regarding middleweight carcasses. Fat weight estimation was more uniform compared to muscle (except for light carcasses). A variety of factors, such as genetic differences and dissection quality, may be causing the observed discrepancies.

**Table 3b.** Means of CT carcass composition parameters for each live weight category per species

<b>Carcass Composition</b>						
	<b>muscle volume (cm3)</b>	<b>fat volume (cm3)</b>	<b>bone vol (cm3)</b>			
<b>sheep 25%</b>	4350.79	1589.18	965.29			
<b>sheep 35%</b>	5930.28	2152.96	1301.54			
<b>sheep 50%</b>	6738.03	2952.85	1529.63			
<b>sheep 100%</b>	9748.15	9354.78	2871.86			
<b>sheep total</b>	6339.55	3315.42	1518.17			
<b>goats 25%</b>	3034.22	940.01	700.64			
<b>goats 70%</b>	8640.73	4554.37	2046.96			
<b>goats 100%</b>	15656.46	5046.62	3784.99			
<b>goats total</b>	6072.35	2226.84	1439.08			
<b>beef</b>	262848.13	49368.18	33465.93			
	<b>muscle weight (g)</b>	<b>fat weight (g)</b>	<b>bone weight (g)</b>	<b>muscle content (%)</b>	<b>fat content (%)</b>	<b>bone content (%)</b>
<b>sheep 25%</b>	4524.82	1509.72	NA	42.59	13.97	NA
<b>sheep 35%</b>	6167.50	2045.31	NA	43.50	14.30	NA
<b>sheep 50%</b>	7007.55	2805.21	NA	38.63	15.48	NA
<b>sheep 100%</b>	10138.07	8887.04	NA	32.48	28.52	NA
<b>sheep total</b>	6593.13	3149.65	NA	40.47	16.69	NA
<b>goats 25%</b>	3155.59	893.01	NA	39.35	11.08	NA
<b>goats 70%</b>	8986.36	4326.65	NA	41.60	20.03	NA
<b>goats 100%</b>	16282.72	4794.29	NA	49.95	14.71	NA
<b>goats total</b>	6315.24	2115.50	NA	41.49	13.17	NA
<b>beef</b>	273362.05	46899.77	69638.17	70.13	12.03	17.84

**Table 4.** CT and dissection data comparison – (1) Dissection estimation: Means by live weight category, (2) CT estimation: Means by live weight category, (3) Difference between carcass tissue weight by CT and dissection, (4) Difference between carcass tissue weight estimated by CT and dissection as percentage of tissue weight by dissection

**1 - DISSECTION DATA**

	total carcasses	carcass weight (g)	muscle weight (g)	fat weight (g)	muscle content (%)	fat content (%)
sheep 25%	26	10204	4079.54	1159.69	49.63	13.80
sheep 35%	20	14447	5724.30	1947.80	48.84	16.31
sheep 50%	15	18797	7296.67	2991.47	47.60	19.25
sheep 100%	21	30095	12315.33	8608.19	40.93	28.60
sheep total	82	18386	7353.96	3676.79	46.75	19.49

**2 - CT DATA**

	total carcasses	carcass weight (g)	muscle weight (g)	fat weight (g)	muscle content (%)	fat content (%)
sheep 25%	3	10667	4524.82	1509.72	42.59	13.97
sheep 35%	4	14200	6167.50	2045.31	43.50	14.30
sheep 50%	3	18133	7007.55	2805.21	38.63	15.48
sheep 100%	2	31200	10138.07	8887.04	32.48	28.52
sheep total	13	16908	6593.13	3149.65	40.47	16.69

**3 - DIFFERENCE**

	carcass weight (g)	muscle weight (g)	fat weight (g)	muscle content (%)	fat content (%)
sheep 25%	462.63	445.28	350.03	-7.05	0.17
sheep 35%	-247.30	443.20	97.51	-5.34	-2.01
sheep 50%	-663.87	-289.12	-186.26	-8.98	-3.77
sheep 100%	1104.76	-2177.26	278.85	-8.44	-0.08

**4 - DIFFERENCE (%)**

	carcass weight (g)	muscle weight (g)	fat weight (g)	muscle content (%)	fat content (%)
sheep 25%	4.53	10.92	30.18	-14.20	1.25
sheep 35%	-1.71	7.74	5.01	-10.93	-12.33
sheep 50%	-3.53	-3.96	-6.23	-18.86	-19.57
sheep 100%	3.67	-17.68	3.24	-20.63	-0.29

## 5 Next Steps and Implementation Perspectives

This is the first study to implement CT as a carcass evaluation tool in Greece. Preliminary results presented in this manuscript indicate potential in this field. Our next tasks focus on the enrichment of the sample with more CT-scanned carcasses and the inclusion of dissection data that will directly validate the results.

Standardization of a carcass evaluation protocol, based on non-destructive methods, can significantly change meat industry in Greece. Accurate and easy carcass quality evaluation will facilitate high-quality meat production, competitive against imported special cuts and able to reach high selling prices. Objective quality perception will permit grading of different meat cuts, thus allowing for better produce capitalization and waste minimization. This effort will form a value chain, rewarding quality meat producers, creating bigger profit margins and meeting consumer demands.

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## References

1. Anderson, F., Williams, A., Pannier, L., Pethick, D.W. and Gardner, G.E. (2015) Sire carcass breeding values affect body composition in lambs— 1. Effects on lean weight and its distribution within the carcass as measured by computed tomography. *Meat Science*, 108, p.145-154.
2. Anderson, F., Williams, A., Pannier, L., Pethick, D.W. and Gardner, G.E. (2016) Sire carcass breeding values affect body composition in lambs— 2. Effects on fat and bone weight and their distribution within the carcass as measured by computed tomography. *Meat Science*, 116, p.243-252.
3. Anderson, F., Cook, J., Williams, A. and Gardner, G.E. (2018) Computed tomography has improved precision for prediction of intramuscular fat percent in the *M. longissimus thoracis et lumborum* in cattle compared to manual grading. *Meat Science*, 145, p.425-430.
4. Arsenos, G. (1997) Effect of genotype and management factors on fatty acid composition of carcass fat in Boutsko, Serres and Karagouniko lambs. PhD thesis. Aristotle University of Thessaloniki.
5. Bünger, L., MacFarlane, J.M., Lambe, N.R., Conington, J., McLean, K.A., Moore, K., Glasbey, C.A. and Simm, G. (2011) Use of X-ray computed tomography (CT) in UK sheep production and breeding. In: *CT Scanning – Techniques and Applications*, Ed.: Subburaj, K., IntechOpen.
6. Clelland, N., Bunger, L., McLean, K.A., Conington, J., Maltin, C., Knott, S. and Lambe, N.R. (2014) Prediction of intramuscular fat levels in Texel lamb loins using X-ray computed tomography scanning. *Meat Science*, 98(2), p.263-271

7. Daumas, G. and Monziols M. (2011) An accurate and simple computed tomography approach for measuring the lean meat percentage of pig cuts. In: Proceedings of the 57<sup>th</sup> International Congress of Meat Science and Technology, Ghent, Belgium.
8. Daumas, G. and Monziols M. (2016) X-ray computed tomography: reference for pig classification. *Cahiers IFIP*, 3(1), p.59-70.
9. Eknæs, M., Chilliard, Y., Hove, K., Inglingstad, R.A., Bernard, L. and Volden, H. (2017) Feeding of palm oil fatty acids or rapeseed oil throughout lactation: Effects on energy status, body composition, and milk production in Norwegian dairy goats. *Journal of Dairy Science*, 100(9), p.7588-7601.
10. Karamichou, E., Richardson, R.I., Nute, G.R., McLean, K.A. and Bishop, S.C. (2006) Genetic analyses of carcass composition, as assessed by X-ray computer tomography, and meat quality traits in Scottish Blackface sheep. *Animal Science*, 82(2), p.151-162.
11. Lambe, N.R., Young, M.J., McLean, K.A., Conington, J. and Simm, G. (2003) Prediction of total body tissue weights in Scottish Blackface ewes using computed tomography scanning. *Animal Science*, 76(2), p.191-197.
12. MacFarlane, J.M., Lewis, R.M., Emmans, G.C., Young, M.J. and Simm, G. (2006) Predicting carcass composition of terminal sire sheep using X-ray computed tomography. *Animal Science*, 82(3), p.289-300.
13. Matika, O., Riggio, V., Anselme-Moizan, M., Law, A.S., Pong-Wong, R., Archibald, A.L. and Bishop, S.C. (2016) Genome-wide association reveals QTL for growth, bone and in vivo carcass traits as assessed by computed tomography in Scottish Blackface lambs. *Genetics Selection Evolution*, 48(11).
14. Ministry of Rural Development and Food (2018)  
<http://www.minagric.gr/index.php/el/statistika-stoixeia-kreatos-sfagion/file/>.  
Accessed: 09/04/2020
15. Navajas, E.A., Glasbey, C.A., McLean, K.A., Fisher, A.V., Charteris, A.J.L., Lambe, N.R., Bünger, L. and Simm, G. (2006) In vivo measurements of muscle volume by automatic image analysis of spiral computed tomography scans. *Animal Science*, 82(4), p.545-553.
16. Navajas, E.A., Glasbey, C.A., Fisher, A.V., Ross, D.W., Hyslop, J.J., Richardson, R.I., Simm, G. and Roehe, R. (2010a) Assessing beef carcass tissue weights using computed tomography spirals of primal cuts. *Meat Science*, 84(1), p.30-38.
17. Navajas, E.A., Richardson, R.I., Fisher, A.V., Hyslop, J.J., Ross, D.W., Prieto, N., Simm, G. and Roehe, R. (2010b) Predicting beef carcass composition using tissue weights of a primal cut assessed by computed tomography. *Animal*, 4(11), p.1810-1817.
18. Németh, T., Nyisztor, J., Kukovics, S., Kupai, T., Lengyel, A. and Toldi, G. (2010) Body composition of crossbred kids evaluated by computed tomography. *Acta Agraria Kaposváriensis*, 14(2), p.273-276.
19. Sørensen, M.T. (1992) In vivo prediction of goat body composition by computer tomography. *Animal Science*, 54(1), p.67-73.

20. White, D.R., Booz, J., Griffith, R.V., Spokas, J.J. and Wilson, I.J. (1989) Report 44: Tissue substitutes in radiation dosimetry and measurement. Journal of the ICRU, 23(1).
21. White, D.R., Griffith, R.V. and Wilson, I.J. (1992) Report 46: Photon, electron, proton and neutron interaction data for body tissues. Journal of the ICRU, 24(1).