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Studies for meat amount estimation by multiple regression using ultrasound and carcass measurements on Carpatina kids*

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Meat quality is relatively important for consumers and is accomplished by improving carcass quality in animals designated for meat production. The purpose of this study was to estimate carcass meat quantity by ultrasound and non-linear multiple regression equations. The measurements were conducted on 22 Carpatina kids aged 5.5 months, in two points (P_1 – 5 cm from the spine, in line with the 12th rib; P_2 – between the 3rd and 4th lumbar vertebra) of the Longisimus dorsi muscle to obtain subcutaneous fat layer thickness (2.02, 1.93 mm), muscle depth (21.05, 20.19 mm), muscle eye area (9.99, 9.71 cm^2) and muscle perimeter (130.45; 130. 02 mm). Meat quantity was estimated with coefficients of determination by non-linear multiple regression equations, using four ultrasound parameters, measured in P_2 for live weight, semi carcass and carcass weight (0.93), and also in commercial cuts, leg and rack (0.91; 0.90), followed by loin and shoulder (0.86, 0.85). The meat amounts obtained by ultrasound measurements were established in P_2 with the best estimation for commercial cuts, loin and shoulder (0.94, 0.94), followed by leg and rack (0.92, 0.90). Very good meat estimation was obtained using four ultrasound parameters in P_1 for live weight (0.93), semi carcass (0.92) and carcass weight (0.91) and in commercial cuts, leg and rack (0.91, 0.90), followed

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by loin and shoulder (0.86; 0.85). The non-linear multiple regression equations developed in this study by ultrasounds showed very high precision coefficients, by estimating meat production and by improving the evaluation of Carpatina goats selected for meat quality.

KEY WORDS: carcass / Carpatina goat / commercial cuts / non-linear multiple regression / ultrasound

The Real Time Ultrasound technique in goats shows great potential for *in vivo* evaluation of carcass composition and meat traits. Recently several works have clearly shown that the ultrasound technique provides good estimations for carcass meat composition in goats facilitating prediction of carcass composition both in adult animals and in young age groups such as kids. The goat population accounts for 25 % of the total world population of ruminants [FAO 2010]. Goat meat represents 6.5 % of the world's ruminant meat production [FAO 2010]. The nutritional value of goat meat is high, since it has 10% more lean meat than beef carcasses and 19% more lean meat than lamb carcasses, thus it is attractive for consumers [Amoah and Gelaye 2003]. The EUROP system (E – excellent, U – Very Good, R – Good, O – Fair and P – Poor) is mainly directed to improve carcass meat production in the European market by helping farmers in goat breeding and selection. The EUROP classification meets food quality and safety requirements of consumers, facilitating an objective meat evaluation for payment in agreement with its quality. Ultrasound is recommended as a noninvasive technique for the estimation of meat carcass composition early in the animals' life [Teixeira *et al*. 2008]. The ultrasound can accurately predict the LD muscle area, LD muscle depth and backfat thickness [Leeds *et al.* 2008]. Also the amounts of muscle, subcutaneous fat, intermuscular fat and total fat can be accurately predicted based on ultrasound measurements [Silva *et al.* 2006, Teixeira *et al.* 2006]. Therefore, the ultrasound method may provide breeders, producers and researchers with an ability to estimate carcass composition traits *in vivo*, contributing to precision of breeding [Leeds *et al.* 2007]. The Carpatina breed has a body conformation for milk production (500-700 kg) and its population is growing in mountainous areas having 160% prolificacy. The average daily gain for kids in the weaning period is 150 grams and after that it may reach up to 200 grams per day between 2.5 and 5.5 months. Romania ranks 4th regarding goat population after Great Britain, Spain and Greece. Multiple studies have shown the purpose of the livestock and meat market is to establish an objective method for meat quality evaluation in goats and to determine it in live animals [Stanford *et al.* 1995, Dhanda *et al.* 1998, Pathak *et al.* 2011]. The resulting high quality products will be beneficial for humans by preventing and controlling the incidence of heart disease and atherosclerosis. Studies have revealed that goat meat fat content is lower by 50-60% compared to beef, by 42-59% compared to the lamb and by 25% compared to veal [Banskalieva *et al*. 2000]. The ultrasound method used in this study on Carpatina kids allowed us to determine early in their life time if they can be selected for carcass meat quality. Ultrasound parameters measured on the *Longissimus dorsi* muscle (LD) (subcutaneous fat depth, eye muscle area, muscle depth, eye muscle perimeter) in the present research are correlated with classical measurements (live weight, carcass weight and commercial cuts). Based on these measurements, meat quantity in Carpatina goats was estimated by non-linear multiple regression equations. Carcass dissection and measurements, as well as physicochemical analyses are time-consuming and very expensive and the selected animals may no longer be used for reproduction. Multiple studies have been undertaken to remove this inconvenience and to solve this problem by predicting body weight and LD muscle area using body measurements in subtropical goat kids [Abdel–Mageed *et al.* 2013]. Recently, Silva *et al*. [2012] dedicated an entire chapter in their very well documented study to the application of ultrasound, making remarks on the imaging control methods developed for meat quality control using such techniques as CT scan, ultrasound and Visual Imaging Analysis in different species (beef, pig and sheep carcass grading of breeding animals for meat quality). These may be used to help farmers to optimise the meat production system in agreement with the preferable market characteristics [Ferguson 2004]. The *in vivo* evaluation of goat carcasses was conducted based on real-time ultrasound measurement in many studies to predict carcass characteristics in Alpine goats [Stanford *et al*. 1995], crossbreed Spanish goats [Mesta *et al*. 2004] and in Serrana kids [Monteiro 2010]. Using the same technique, Teixeira *et al*. [2008] obtained *in vivo* estimations for goat carcass composition in the Spanish Celtiberica breed. Similar studies found relationships between ultrasound results and carcass measurement *in live* goats [Defta *et al.* 2000] and lambs [Hajji *et al.* 2015].

Recently, a study was conducted by Lazar *et al*. [2016] to estimate meat amount applying non-linear multiple regression equations, using *in vivo* and carcass measurements in Teleorman Black Head lambs. The purpose of this study was to evaluate goat meat quality using the most efficient and non-invasive method of investigation that in the last decade had already been successfully tested on the Romanian sheep breed with great results. This ultrasound procedure was adopted and used for the first time for Carpatina goats in Romania, hoping to improve the selection methodology of this local goat breed by emphasizing its advantages offered to breeders and farmers. In Romania goat meat classification until now was performed using the conventional method by slaughtering the animals and thus removing them from reproduction. This preliminary research aims to solve this problem, to eliminate this inconveniency by keeping the best goats and spreading the genetic gain in the next generation thanks to the application of the non-invasive ultrasound parameters. Based on ultrasound parameters (subcutaneous fat layer thickness, muscle depth, muscle eye area and perimeter of the muscle area of the LD muscle) closely correlated with the classical carcass measurements a non-linear multiple regression equation was developed to estimate meat quantity in the Carpatina breed in order to establish the most appropriate model with four and three ultrasound parameters in these two measuring points located close to the spine at the *Longissimus Dorsi* muscle level, as being very well correlated with meat quality.

Material and methods

Animals

Animals were cared for in accordance with the Romanian Law 206/2004 and the EU Council Directive 98/58/EC for handling and protection of animals used for experimental purposes. The study protocol was approved by the Ethical Committee of the National Research-Development Institute for Animal Nutrition and Biology, Balotesti, Romania (Ethical Committee no. 52/2014). No veterinary drugs were used during the experimental period. The study was conducted on 22 Carpatina kids aged 5.5 months in a farm in the Teleorman County (Romania). Body weight at two months (BWM2) and body weight at 5.5 months (BWM5.5) were measured in order to determine the average body weight gain (ABWG).

Ultrasound measurements

The ultrasound measurements were performed with an Echo Blaster 64 with an LV 7.5 65/64 probe (TELEMED ultrasound medical systems, Lithuania). All ultrasound images were recorded and analysed with the Echo Wave II 1.32 software (http://www.telemed.lt, info@telemed.lt, Lithuania). The first measuring point (P_1) was located 5 cm from the spine, in line with the 12th rib, while the other measuring point (P_2) was located between the 3rd and 4th lumbar vertebrae. A large proportion of *Longisimus dorsi* (LD) muscle is situated between these two measuring points and provides information which is important for the evaluation of meat production in kids, i.e. subcutaneous fat layer thickness (FP_1, FP_2), muscle depth (MP_1, MP_2), muscle eye area (AP_1, AP_2) and muscle perimeter (PP_1, PP_2) at the 12th rib and between the 3rd and 4th lumbar vertebrae of the LD muscle, respectively.

Slaughter carcass measurements

Animals were prepared for slaughter and for the preceding 24-hour period they were not fed and received only water. They were weighed alive and then slaughtered in order to perform carcass measurements on 12 kids. Carcasses were cut and prepared by the French method described by Flamant and Boccard [1966], producing five commercial cuts: leg, loin, rack, shoulder, flank and neck. Each commercial cut was weighed after carcass dissection and then deboned into meat and bones with the calculation of commercial yield, slaughterhouse yield, the meat : bone ratio and bone percentage.

Statistical analysis

Simple correlations were calculated between ultrasound (subcutaneous fat layer thickness, muscle depth, muscle eye area, muscle perimeter) and classical body measurements (weight at 2 months and at 5.5 months).

Non-linear multiple regression equations Equations for estimating carcass meat content (subcutaneous fat layer thickness, muscle depth, muscle eye area, muscle perimeter of the LD muscle, and commercial cut meat quantity) were established using ultrasound parameters. The Quattro pro X5 software program [Corel Corporation, USA] was used for data calculation to fit the appropriate model and to determine the prediction regression functions. A non-linear multiple regression equation with four variables was obtained:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$$

where:

y – meat amount in half carcass, carcass, leg, loin, rack, shoulder, flank, neck;

$a_1, a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8$ – regression coefficients;

b – intercept;

x_1, x_2, x_3, x_4 – subcutaneous fat layer thickness, muscle depth, muscle eye area and the LD muscle perimeter, respectively.

Non-linear multiple regression equations were also established to estimate carcass and half carcass meat quantity, using three ultrasound parameters (muscle depth, muscle eye area, and LD muscle perimeter):

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$$

where:

y – meat amount in half carcass, and carcass;

$a_1, a_2, a_3, a_4, a_5, a_6$ – regression coefficients;

b – intercept;

x_1, x_2, x_3 – muscle depth, muscle eye area and LD muscle perimeter, respectively.

The computations were performed using the Quattro pro X5 software package [Corel Corporation, USA].

Results and discussions

Body weight

The average kid body weight at two months was 16.19 kg, reaching 31.08 kg at the age of 5.5 months. The average daily gain was 0.14 kg in 103 days until slaughter age (Tab. 1). Regarding the evolution of body weight between weaning weight and 5.5

Table. 1 Body weight and average daily gain of Carpatina kids

Trait	Mean	Standard error	Variability coefficient (%)
Body weight at 2 months (kg)	16.19	1.48	31.83
Body weight at 5.5 month (kg)	31.08	1.73	19.26
Total gain (kg)	14.88	1.32	30.81
Average daily gain (kg)	0.14	0.01	30.81
Age (days)	103		

months, the Carpatina kids showed that this breed has the potential to improve meat carcass quality.

Ultrasound measurements

Numerous tools for investigation may be applied, one of them being ultrasound measurement, a modern technique, easy to use, rapid and non-invasive. Ultrasound has permitted to accomplish this goal using modern equipment which is easy to operate, provides accurate imaging with great repeatability at a relatively low cost. Until now in Romania carcass measurements in goats have been made by the classical method involving sacrificing the animals, while ultrasound is a very good choice to obtain a better evaluation of meat quality *in vivo*. The ultrasound measurements of Carpatina kids taken in this preliminary study were recorded within the limits cited in the literature for goat breeds. The subcutaneous fat layer at the age of 5.5 months ranged between 1.93 mm and 2.02 mm (Tab. 2). This technique allowed to record images reflecting the body structure and composition and thus permitting to investigate LD muscle depth, which has medium values (20 mm) in goat breeds specialized for meat production (Nubian, Spanish, Boer), similar with the muscle depth obtained in Carpatina kids. The measurements and carcass characteristics of goats started to be of major importance after the application of the ultrasound method, as showed by Mesta *et al.* [2004] in their study, in which they compared ultrasound measurements in live animals with their carcass quality after slaughter. Ultrasound measurements were made in that study on Spanish goats for fat thickness (9 mm), LD muscle area (6.65 cm^2), LD muscle depth (2.44 cm). Also, linear regression analysis was conducted between ultrasound and carcass measurements in Spanish goats, indicating that not many carcass characteristics could be used to establish models for a very good estimation capacity [Mesta *et al*. 2004]. The *Longissimus* muscle area (LMA) was 9.56 cm^2 in Egyptian kids, while in the present research on Carpatina kids it was slightly higher at 9.99 cm^2. Carpatina

Table. 2. Ultrasound measurements of Carpatina kids

Trait	Mean	Standard error	Variability coefficient (%)	*P*-value
Subcutaneous fat layer thickness in P_1[1] (FP_1), mm	2.02	0.06	10.75	NS
Subcutaneous fat layer thickness in P_2[2] (FP_2), mm	1.93	0.07	12.73	
Muscle depth in P_1 (MP_1), mm	21.05	0.59	9.67	NS
Muscle depth in P_2 (MP_2), mm	20.19	0.63	10.74	
Muscle eye area in P_1 (AP_1), cm^2	9.99	0.28	9.87	NS
Muscle eye area in P_2 (AP_2), cm^2	9.71	0.26	9.40	
Muscle perimeter in P_1 (PP_1), mm	130.45	1.78	4.72	NS
Muscle perimeter in P_2 (PP_2), mm	130.02	3.89	4.40	

[1]P_1 – point 1 located 5 cm from the spine, in line with the 12th rib; [2]P_2 – point 2 located between the 3rd and 4th lumbar vertebrae; NS – P>0.05.

kids had a backfat thickness that was almost double (1.93 and 2.02 mm) than that of Egyptian goats (Zaraibi, Barki, Damascus 1.0, 1.01 mm). All these traits studied *in vivo* are very important for the livestock and meat market to classify the animals using an accurate measurement method [Abdel-Mageed *et al.* 2013]. The benefits of real time ultrasound are that it does not affect the product while being able to predict carcass quality, to determine the value and merit in live animals [Teixeira *at al.* 2008]. In turn, Stanisz *et al.* [2004] made a study in the same manner with the present research, where White kids had the LD eye muscle area of 8.05 cm^2, being 20% lower than in Carpatina kids (9.99 cm^2). Regarding the LD muscle depth, in White kids it was 21.92 mm, slightly higher than in Carpatina kids (21.05, 20.19 mm). The conclusion presented by Stanisz *et al*. [2004] was that ultrasound is useful in the estimation of meat, fat and bone contents. Carpatina kids show that they have a potential for a very good LD muscle eye area in the limits known for a goat breed specialized for meat production (9.99 cm^2). In the present research also the LD muscle perimeter was measured, which provides information regarding its size and being a very good indicator of meat quality. No significant differences were found between these two ultrasound measurement points for subcutaneous fat layer, muscle depth, muscle eye area and muscle eye perimeter of the LD muscle (Tab. 2).

Slaughter measurements

After slaughter, the Carpatina kids were measured to determine their meat and bone contents. The cold dressing percentage and commercial yield were calculated (44.87 and 50.53%) for Carpatina kids. Commercial cuts of very good meat quality were obtained after dressing, with high percentages for leg (29.08%) and loin (7.51%), the two pieces that contain the LD muscle, representative for meat quality. The meat : bone ratio obtained in this preliminary study from the Carpatina kids was 1 : 2.89, with a very good representation for meat quantity. This gives a clear image of the Carpatina goat breed, which can be improved by selection for carcass quality. The bone ratio after calculations represented 25.87% of the entire carcass (Tab. 3). Medium quality meat was found in the shoulder (21.33%), flank (19.33%) and neck (12.51%) (Tab. 3). Meat and bone contents of the commercial cuts are given in Table 4, with the shoulder ranking 1st with 78.87 % meat followed by the leg (74.25%). The loin and rack together describe the LD muscle, they have the best quality meat and almost the same quantity (66.52 and 66.44%). A low bone content was recorded in the shoulder (21.13%), followed closely by the flank (21.64%). A medium content of bones was found in the leg (25.75%), whereas high bone contents were obtained in the loin and rack. A study was conducted by Stanisz *et al*. [2004] using ultrasound measurements in order to asses slaughter value of male White goats at the age of 105 days, similar to the growing stage of the Carpatina kids (103 days). At slaughter the Carpatina kids had a body weight of 31.08 kg, which was almost 23% higher than in White goat kids (24.85 kg) **[**Stanisz *et al*. 2004]. Multiple studies are necessary to determine body composition in different growth stages of goats, especially young ones, which change

Table 3. Commercial cut weights, meat : bone ratio, bone percentage and slaughter and commercial yields in 5.5-month-old Carpatina kids

Trait	Mean	Standard error	Variability coefficient (%)	Half carcass percent (%)
Cuts weight (kg)				
leg	1.92	0.12	21.12	29.08
loin	0.50	0.04	28.91	7.51
rack	0.68	0.05	24.51	10.24
shoulder	1.41	0.09	23.44	21.33
flank	1.28	0.09	24.12	19.33
neck	0.84	0.07	29.21	12.51
half carcass	4.99	0.22	15.54	100.00
Meat : bone ratio	2.89			
Bone ratio (%)	25.87			
Slaughter yield (%)	44.87			
Commercial yield (%)	50.53			

Table. 4. Meat and bone contents in commercial cuts of Carpatina kid carcasses

Cuts (kg)		Mean weight (kg)	Standard error	Variability coefficient (%)	Percentage from cuts (%)
Leg	meat	1.42	0.09	21.65	74.25
	bone	0.49	0.03	24.38	25.75
Loin	meat	0.34	0.03	32.83	66.52
	bone	0.17	0.01	28.22	33.48
Rack	meat	0.45	0.03	22.72	66.44
	bone	0.23	0.02	33.38	33.56
Shoulder	meat	1.12	0.08	25.99	78.87
	bone	0.29	0.02	21.54	21.13
Flank	meat	1.01	0.08	26.42	78.36
	bone	0.27	0.02	21.97	21.64
Neck	meat	0.62	0.06	32.89	73.00
	bone	0.22	0.01	22.71	27.00
Half carcass	meat	4.96	0.35	24.57	74.79
	bone	1.67	0.09	20.26	25.21

rapidly and must have very good carcass quality. Techniques based on ultrasound are of great importance in animal science because they prevent damage to the carcass in live animals and inflict no pain in the process. Since the beginning this technique of real time ultrasound has been considered an accurate tool for the evaluation of carcass composition and meat structure [Silva *et al*. 2012]. Studies regarding classical body measurements were conducted for body weight after weaning by Abdel-Mageed *et al.* (2013), who obtained 16.27 kg, similar to the weaning weight measured in Carpatina kids (16.19 kg). Very precise predictions were obtained by Abdel-Mageed *et al.* (2013) in subtropical kids of three Egyptian goat breeds (Zaraibi, Damascus, Barki), for body weight and LD muscle area using ultrasound measurements, regression equations and correlation analysis, similar to the present research. The cold dressing percentage in the

Carpatina kids was slightly lower than that of White kids (46.92%). The bone ratio in the Carpatina kids was 25.87%, while in White kids it was 24.61% [Stanisz *et al*. 2004].

Correlations between classical carcass measurements and ultrasound results

In the Carpatina kids simple correlations were found between carcass data (body weight at 2 and 5.5 months) with ultrasound measurements (LD fat depth, LD muscle depth, LD eye muscle area, LD eye muscle perimeter) (Tab. 5). Three correlation intervals resulted between carcass and ultrasound measurements with limits ranging between 0.03-0.24 for small correlations, 0.39-0.47 for medium to high correlations and high correlations (0.49-0.83). Body weight at 5.5 month was highly correlated with LD muscle depth (0.73, 0.83) and with LD eye muscle area (0.82, 0.81). Medium correlations were found between body weight at 5.5 months and LD eye muscle perimeter in points P_1 and P_2, where measurements were taken (0.69, 0.59). The LD fat depth gave small to medium correlations with body weight at 5.5 months in P_1 (0.24) and in P_2 (0.49) – Table 5.

Table 5. Correlations between body weight measurements (at 2 and at 5.5 months) and ultrasound carcass measurements performed in Carpatina kids

Trait	BW2M	BW5.5M
BW5.5M	0.67**	1.00
FP_1	0.39*	0.24*
FP_2	0.37*	0.49**
MP_1	0.56**	0.73**
MP_2	0.47**	0.83**
AP_1	0.82**	0.82**
AP_2	0.51**	0.81**
PP_1	0.82**	0.69**
PP_2	0.59**	0.59**

BW2M – body weight at two months; BW5.5M – body weight at 5.5 months; FP_1 – subcutaneous fat layer thickness in point 1 located 5 cm from the spine, in line with the 12th rib (P_1); FP_2 – subcutaneous fat layer thickness in point 2 located between the 3rd and 4th lumbar vertebrae (P_2); MP_1 – muscle depth in P_1; MP_2 – muscle depth in P_2; AP_1 – muscle eye area in P_1; AP_2 – muscle eye area in P_2; PP_1 muscle perimeter in P_1; PP_2 – muscle perimeter in P_2; * – significant correlations at $P<0.05$; ** – highly significant correlations at $P<0.01$.

The simple correlations were calculated between classical carcass measurements (carcass meat content in commercial cuts and commercial cuts with ultrasound measurements in the Carpatina kids (Tab. 6). A total of 136 pairs of traits were analysed for correlations to identify the best combinations, which showed that 41.91% of the trait pairs showed strong correlations, followed by 45.59 % with moderate correlations and only 12.5% with small correlations. Strong correlations were determined in the

Carpatina kids in the present research between carcass weight and LD muscle depth and LD muscle eye area in P_1 (0.77, 0.86) and in P_2 (0.81, 0.87). Moderate correlations were determined in the Carpatina kids between carcass with LD fat depth in P_2 (0.52) and between commercial cuts (leg, loin, rack, shoulder) with LD fat depth (0.45, 0.41, 0.40, 0.50). Very strong correlations were determined in this study between carcass

Table 6. Correlations between classical carcass measurements (carcass and commercial cuts weights) and ultrasound measurements of 5.5-month-old Carpatina kids

Trait	Carcass	Leg	Loin	Rack	Shoulder	Flank	Neck	P leg	FP_1	FP2	MP_1	MP_2	AP_1	AP_2	PP_1
Leg	0.96**														
Loin	0.95**	0.92**													
Rack	0.89**	0.81**	0.87**												
Shoulder	0.97**	0.97**	0.88**	0.81**											
Flank	0.94**	0.90**	0.94**	0.82**	0.89**										
Neck	0.93**	0.92**	0.84**	0.82**	0.90**	0.82**									
P leg	0.87**	0.88**	0.77**	0.81**	0.84**	0.80**	0.88**								
FP_1	0.37*	0.32*	0.31*	0.35*	0.31*	0.25**	0.47**	0.20*							
FP_2	0.50**	0.45**	0.41**	0.40**	0.50**	0.36*	0.48**	0.60**	0.06						
MP_1	0.77**	0.75**	0.71**	0.52**	0.74**	0.77**	0.72**	0.69**	0.34*	0.64**					
MP_2	0.81**	0.79**	0.83**	0.79**	0.78**	0.75**	0.82**	0.65**	0.20*	0.36*	0.55**				
AP_1	0.86**	0.87**	0.86**	0.81**	0.87**	0.84**	0.73**	0.65**	0.38*	0.37*	0.65**	0.77**			
AP_2	0.87**	0.76**	0.88**	0.90**	0.74**	0.82**	0.77**	0.79**	0.37*	0.61**	0.68**	0.68**	0.72**		
PP_1	0.75**	0.74**	0.76**	0.79**	0.76**	0.66**	0.62**	0.50**	0.43**	0.32*	0.42**	0.71**	0.94**	0.67**	
PP_2	0.73**	0.63**	0.62**	0.68**	0.67**	0.62**	0.65**	0.65**	0.57**	0.45**	0.49**	0.27*	0.53**	0.75**	0.54

FP_1 – subcutaneous fat layer thickness in point 1 located 5 cm from the spine, in line with the 12th rib (P_1); FP_2 – subcutaneous fat layer thickness in point 2 located between the 3rd and 4th lumbar vertebrae (P_2); MP_1 – muscle depth in P_1; MP_2 – muscle depth in P_2; AP_1 – muscle eye area in P_1; AP_2 – muscle eye area in P2; PP1 – muscle perimeter in P_1; PP_2 – muscle perimeter in P2; P leg- leg perimeter; * – significant correlations at $P<0.05$; ** – highly significant correlations at $P<0.01$.

weight and LD muscle depth in P_1 (0.77) and P_2 (0.81), and with LD muscle eye area in the same measurement points (0.87, 0.76). The leg and loin are commercial cuts, which together made up the *Longissimus dorsi* muscle, and they are very well correlated with carcass meat quantity and quality. Both commercial cuts mentioned above are mostly correlated with carcass weight for leg (0.87, 0.76) and loin (0.86, 0.88). Also, the LD muscle eye perimeter is correlated with leg (0.74, 0.73) and loin (0.76, 0.72) in P_1 and P_2 (Tab. 6). In the present research the Carpatina kids showed a higher correlation for carcass weight with the same combination of traits (leg and loin) in both measurement points (0.86, 0.87).

Pearson's correlations were calculated between carcass body weight with the *Longissimus* muscle area (0.86, 0.87) and subcutaneous fat thickness (0.37, 0.50) in both measurement points in the Carpatina kids compared with Egyptian kids, for which high correlations were recorded with similar values (0.89 and 0.67) [Abdel-Mageed *et al*. 2013]. In that study high correlations between body weight and the *Longissimus* muscle area were found, confirming again the positive relationship useful in meat quality evaluation obtained by the non-invasive method. Abdel-Mageed *et al*. [2013] in their study emphasized the importance of ultrasound in the evaluation of goat meat characteristics and at the same time providing their more reliable prediction. Several studies indicated significant positive correlations for the same traits between ultrasound and carcass measurements in small ruminants [Leeds *et al*. 2008, Stanisz *et al*. 2004, Teixeira *et al*. 2008]. Also, they discovered no significant differences in the *Longissimus* muscle area and muscle depth with a very good accuracy of 97-100%. Stanisz *et al*. [2004] concluded that ultrasound may easily show a positive connection between the *Longissimus* muscle area and carcass lean meat and fat contents, as well as the proportion of important cuts in the carcass of White goats, similar to the results of the present study for Carpatina goats. Ultrasound has proven to be useful in predicting the circumference of the *Longissimus* muscle area and furthermore, in a simple manner to predict total carcass muscle content in sheep [Abdel-Mageed *et al.* 2013]. Correlations revealed a strong relationship between ultrasound results and carcass characteristics for fat thickness (0.49), *Longissimus* muscle area (0.75), and *Longissimus* muscle depth (0.71), similar with other studies in beef, pork and sheep reported by Mesta *et al*. [2004] in their publication.

Strong correlations were determined for the Carpatina kids in the present research between carcass weight and LD muscle depth and LD muscle eye area in P_1 (0.77, 0.86) and in P_2 (0.81, 0.87), similar with those reported by Abdel-Mageed *et al.* [2013] at 0.89 in the Zairibi, Damascus and Barki kids and higher than those reported by Mesta *et al.* [2004] in Spanish goats (0.75, 0.71). Moderate correlations were determined for these traits in the Carpatina kids between carcass with LD fat depth in P_2 (0.52) and between commercial cuts: leg, loin, rack, shoulder with LD fat depth (0.45, 0.41, 0.40, 0.50), slightly lower than those reported by Abdel-Mageed *et al.* [2013] in Spanish goats(0.67, 0.52). Very strong correlations were determined in this preliminary study between carcass weight and LD muscle depth in P_1 (0.77) and P_2

(0.81), and LD eye muscle area in the same measurement points (0.87, 0.76), stronger than those reported by Mesta *et al.* 2013 (0.75, 0.52). The leg and loin are commercial cuts very well correlated with carcass meat quantity and quality, mostly correlated with carcass weight in both measurement points for leg (0.87, 0.76) and loin (0.86, 0.88). Also the LD eye muscle perimeter (0.74, 0.73) is moderately correlated with leg (0.76, 0.72) and loin in P_1 and P_2 (Tab. 6). Relationships between live weight and body condition in Angora goats were studied by ultrasound to identify carcass attributes by correlations and to establish the most appropriate combination to provide better evaluations [McGregor *et al.* 2017]. Carcass weight was correlated with LD muscle eye depth for Angora goats at a medium level (0.55).

Non-linear multiple regression equations to estimate meat quantity

When investigating improvement of carcass quality for the Carpatina breed this preliminary study indicated several variants of the multiple regression equations presented in Tables 7 and 8; nevertheless, in practice they need to be further extended to include a higher number of individuals. These multiple regression equations were analysed in both measurement points using four and three ultrasound parameters closely correlated to the classical carcass measurements. The following arguments may be presented to underline the most suitable ones among all the possibilities in the present study. The explanation starts by the clarification offered in the first case when *multiple regression equations* were used for Carpatina kids and meat content was estimated with high precision, using all the four ultrasound parameters as variables (subcutaneous fat thickness, muscle depth, muscle eye area and muscle perimeter of LD in two measurement points). For semi carcass weight (SCW) high precision was obtained with very good coefficients of determination in both measurement points (0.93, 0.93), followed by carcass weight with the same tendency (0.91, 0.93). All the commercial cuts were analyzed and evaluated focusing on meat quality, very well appreciated by consumers. The leg is one of the most desirable commercial cuts demanded by consumers and estimations were provided by the regression equations with high precision coefficients, in both measurement points being very closely related (0.91, 0.92). Estimations were calculated for the rack, a commercial cut that is known by consumers as the filet or fillet, characterized by very good meat quality; these estimations resulted in a high precision coefficient in both measurement points (0.90, 0.90). Cuts very well appreciated by consumers are the loin (0.85, 0.94) and shoulder (0.86, 0.94), which were estimated with high precision coefficients, followed by the flank (0.94, 0.89) and neck (0.84, 0.92), (Tab. 7).

Secondly, the possibility to investigate three ultrasound parameters as variables was analyzed, with multiple regression equations established for Carpatina kids to estimate carcass meat quantity without backfat thickness of the half carcass and the carcass. By modelling the appropriate type of equation a new method was developed to select the best animals suitable for meat quality production earlier in their lifetime in the Carpatina goat, minimizing the generation interval and obtaining a better genetic progress for a such complex trait as meat. These two types of regression equations with four and three ultrasound parameters proved to improve the selection methodology in the future for the Carpatina goat for meat carcass evaluation and to adapt the classification to meat market requirements of consumers in agreement with the EU Council Regulation for animal welfare and human health.

The multiple regression equation estimated with 3 ultrasound parameters had slightly smaller precision coefficients of determination, beginning with the prediction of body weight at 5.5 months and followed by the estimation of meat content in the commercial cuts. In this case the coefficient of determination obtained for estimating meat carcass weight in P_2 was 0.90, closely followed by P_1 with 0.87. The best high precision estimations were obtained in the same model equation for semi carcass weight in both measurement points P_1 and P_2, with comparable values of 0.93 and 0.92. In the assessment undertaken in this preliminary study each commercial cut was analyzed and the importance of its economic value in meat market classification was considered. The meat amount estimation with 3 ultrasound parameters established by the

Table 7. Regression equations for estimating commercial cuts meat quality according to 4 ultrasound measured parameters (subcutaneous fat layer thickness, muscle depth, muscle eye area and muscle perimeter)

Model	Model	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	b	R^2
$Y_{GMAP-SCW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-63.31	3.56	-9.56	6.47	15.91	-0.08	0.63	-0.03	-344.65	0.92
	P_2	12.3	-1.06	2.01	0.02	-3.29	-0.04	-0.1	-	-19.54	0.93
$Y_{GMAP-CW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-36.56	2.86	-10.84	5.65	9.31	-0.07	0.67	-0.02	-304.74	0.91
	P_2	7.92	-0.98	2.32	0.80	-2.27	0.03	-0.11	-	-67.34	0.93
$Y_{GMAP-BW5.5} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-150.19	16.1	-18.96	14.58	36.39	-0.36	1.34	-0.06	-861.98	0.93
	P_2	40.9	-1.71	24.03	1.85	-10.36	-0.01	-1.17	-0.01	-302.75	0.93
$Y_{GMAP-LW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-14.5	0.78	-4.41	2.15	3.71	-0.02	0.26	-0.01	-110.22	0.91
	P2	3.65	-0.68	0.05	0.02	-1.03	0.02	-0.001	-0.0002	3.21	0.92
$Y_{GMAP-LoW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-1.18	0.95	-5.21	2.06	0.37	-0.02	0.29	-0.01	-116.65	0.86
	P_2	1.96	-0.21	0.06	0.27	-0.57	0.01	0.002	-0.001	-17.71	0.94
$Y_{GMAP-RW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-3.08	0.21	-0.95	0.48	0.79	-0.01	0.06	-	25.59	0.90
	P_2	0.78	0.17	0.06	-0.004	-0.2	0.003	0.002	-0.0001	-5.25	0.90
$Y_{GMAP-SW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-6.04	0.8	-1.16	0.57	1.46	-0.02	0.08	-	33.84	0.85
	P_2	1.65	-0.33	1.47	0.14	-0.41	0.01	-0.08	-0.0004	-16.46	0.94
$Y_{GMAP-FW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P1	-1.18	0.95	-5.21	2.06	0.37	-0.02	0.29	-0.01	-116.65	0.94
	P_2	-0.29	-0.28	2.06	0.31	-0.02	0.01	-0.09	-0.001	27.89	0.89
$Y_{GMAP-NW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_1^2 + a_6x_2^2 + a_7x_3^2 + a_8x_4^2 + b$	P_1	-9.9	0.14	2.99	-0.4	2.5	-0.36	-0.14	-	23.05	0.84
	P_2	0.18	0.35	-1.31	0.07	-0.02	-0.01	0.06	-0.001	-3.25	0.92

Y_{GMAP} – meat weight estimation according to 4 ultrasound measured parameters (fat depth, muscle depth, muscle eye area and muscle perimeter) weight of semi carcass (SCW), carcass weight (CW), leg (LW), loin (LoW), rack (RW), shoulder (SW), flank (FW), neck (NW); $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8$ – regression coefficients, b – intercept, x_1, x_2, x_3, x_4 – subcutaneous fat layer thickness, muscle depth, muscle eye area, muscle perimeter.

multiple regression equation ranked first for the shoulder at 0.82 in P_1 and 0.94 in P_2. The precision coefficient for the flank ranked second, amounting in P_1 to 0.91, followed by P_2 with 0.84. In this preliminary research in the Carpatina kids, regarding the most appreciated commercial cut (leg) with very good quality meat high estimations were obtained in P_2 (0.87), slightly higher than in P_1 (0.79). The loin is also a commercial cut known for its best meat quality and it was estimated with high precision of 0.83 in

Table 8. Regression equations estimating meat weight of the half carcass and carcass using 3 ultrasound measured parameters (muscle depth, muscle eye area and muscle perimeter)

Model	Model	a_1	a_2	a_3	a_4	a_5	a_6	b	R^2
$Y_{MAP-SCW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	2.66	-10.11	3.93	-0.06	0.58	-0.02	-233.96	0.84
	P_2	-1.74	5.9	-0.45	0.05	-0.29	0.02	10.66	0.92
$Y_{MAP-CW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	2.16	-7.741	2.98	-0.05	0.46	-0.01	-178.4	0.87
	P_2	-0.71	4.23	0.28	0.02	-0.21	-0.0006	37.93	0.90
$Y_{MAP-BW5.5} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	15.8	-56.47	21.18	-0.36	3.13	-0.08	-1259.57	0.93
	P_2	-3.24	39.22	1.08	0.105	-1.91	-0.002	-239.55	0.92
$Y_{MAP-LW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	0.48	-2.77	0.95	-0.01	0.16	-0.003	-52.6	0.79
	P_2	-0.62	0.98	-0.24	0.01	-0.05	0.001	15.81	0.87
$Y_{MAP-LoW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	0.2	-1.6	0.533	-0.004	0.09	-0.002	28.95	0.83
	P_2	-0.12	0.52	0.13	0.003	-0.02	-0.0005	-10.19	0.78
$Y_{MAP-RW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	0.14	-0.43	0.17	-0.003	0.03	-0.00006	-10.21	0.84
	P_2	0.2	0.18	-0.01	-0.004	-0.008	-	2.29	0.86
$Y_{MAP-SW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	0.8	-2.9	0.92	-0.02	0.16	-0.003	-53.97	0.82
	P_2	-0.55	2.1	0.11	0.01	-0.11	-0.0003	-14.25	0.94
$Y_{MAP-FW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	0.83	-3.3	1.34	-0.02	0.18	-0.005	-79.62	0.91
	P_2	1.17	1.58	0.18	-0.0401	-0.07	-0.0007	-22.28	0.84
$Y_{MAP-NW} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + b$	P_1	-0.30	3.26	-0.92	0.009	-0.16	0.03	46.94	0.73
	P_2	0.2	-1.13	0.10	0.002	0.05	-0.0003	-4.73	0.92

Y_{MAP} – meat estimation according to 3 ultrasound measured parameters (muscle depth, muscle eye area and muscle perimeter) weight of half (semi) carcass (SCW) and carcass (CW), leg (LW), loin (LoW), rack (RW), shoulder (SW), flank (FW), neck (NW)a_1,a_2, a_3, a_4, a_5, a_6 – regression coefficients; x_1, x_2, x_3 – muscle depth, muscle eye area, muscle perimeter; b- intercept.

P_1, followed by 0.78 in P_2. The same trend was closely followed in the case of the rack (0.84, 0.86) and neck (0.73, 0.92) in both measurement points (Tab. 8).

Multiple regression analysis was used for prediction of body weight and LMA in Egyptian kids with very good coefficients of determination of 0.89 and 0.79 [Abdel-Mageed *et al.* 2013]. A similar study was conducted by *in vivo* estimation of goat carcass composition and body fat distribution, where body weight next to the ultrasound measurements were fitted the best multiple regression equation, to predict carcass fat composition [Teixeira *et al*. 2008]. The coefficient of determination amounted to 0.79 and 0.92. Estimation by the regression equation was performed using the variable measured by ultrasound to establish muscle quantity (0.82). These measurements of muscle depth were taken between the first and second lumbar vertebrae, in the fourth sternum vertebra and between the fifth and sixth lumbar vertebrae and were used as variables in regression equations, to establish the subcutaneous fat layer in these three body locations with high precision (0.90, 0.80, 0.88) [Teixeira *et al.* 2008]. In another study [Stanisz *et al*. 2004] regression equations were calculated to estimate slaughter value indicators using ultrasound measurements as variables and very good coefficients of determination were obtained, with precision ranging between 0.44 and 0.97, similar with the precision coefficients obtained for the Carpatina kids. In many studies researchers attempted to determine what happens when a linear multiple regression model combines different factors and observed how they affected meat characteristics that need to be improved. Cadavez *et al*. [2002] developed this type of multiple linear regression equation to predict muscle weight and stated that the aspect and trend was the same for live weight and carcass weight. This explains the variation discovered in muscle weight and comes with confirmation given by the high correlation found between muscle weight and hot carcass weight (0.94). The same author observed an improvement in the quality of meat estimation when a variable was added to the regression model, e.g. fat thickness next to the hot carcass weight. Similar improvements were observed in this preliminary study on Carpatina kids, when better results were obtained using four ultrasound parameters instead of three, next to the classical measurements such as body weight and carcass weight. All these goals help to optimize the meat production system and characteristics necessary for the meat market classification for Carpatina goats. The carcass quality with the desired weight and an optimum amount of muscle and subcutaneous fat tissue ensures that the meat is protected in the chilling process and maximizes the taste and the organoleptic properties so important and appreciated by consumers. The Carpatina breed has the qualities necessary to accomplish these goals and the research will continue investigations using the non-invasive ultrasound technique to obtain a quick response for an earlier selection in their lifetime. The regression equations established in this preliminary study using four ultrasound parameters (subcutaneous fat thickness, muscle eye depth, muscle eye area, muscle eye perimeter) explains the negative regression coefficients for subcutaneous fat thickness obtained in P_1. This is because this measurement point is closer to the leg cut, much better covered in muscles, and this fact may influence the negative value of the regression coefficient. The degree of the regression coefficient negativity depends on the size of the commercial cut used in the evaluation. If the commercial cut is larger, the regression coefficient for the subcutaneous fat layer shows a negative trend, explained by the meat quantity found in each commercial cut (leg, loin, rack, shoulder, flank and neck) and reflected by the first measurement point, P_1. Further investigations need to be conducted and confirm the findings on a significant number of animals to establish the best non-linear multiple regression equations fitted to make a better evaluation in Carpatina kids and to select them for quality meat production.

Recapitulation and conclusions

This preliminary study may be used to improve the selection methodology for the Carpatina goat using the most modern procedure with ultrasound as a non-invasive investigation widely and extensively recognized worldwide in animal breeding for the complex meat traits. The present study on the Carpatina goat proved that the leg (0.87, 0.76) and loin (0.86, 0.88) are commercial cuts very well correlated with carcass meat quantity and quality in both measurement points, while also being two commercial cuts highly appreciated by consumers. Strong correlations were determined in Carpatina kids between carcass weight and LD muscle depth and LD muscle eye area in P_1 (0.77, 0.86) and in P_2 (0.81, 0.87

The ultrasound procedure provided a clear picture of the body structure and composition and the Longissimus dorsi muscle depth of 20 mm in the goat breeds specialized for meat production (Nubian, Spanish, Boer), similar to the muscle depth obtained in the Carpatina kids. The benefits of real time ultrasound stem from the fact that it does not affect the product when predicting carcass quality, to determine the value and merit in live animals.

This preliminary research established multiple regression equations, which gives high precision estimation of meat amount by ultrasound measurements in the Carpatina kids using four ultrasound parameters as variables (subcutaneous fat thickness, muscle depth, muscle eye area and muscle perimeter of LD in two measurement points). The leg is one of the most desired commercial cuts demanded by consumers and estimations were conducted using the regression equations with high precision coefficients in both measurement points being comparable (0.91, 0.92). Results from this present study show that one ultrasound measurement in the *Longissimus dorsi* muscle is enough to estimate carcass meat production in Carpatina kids. Also the Carpatina goat breed proved to have a large potential for meat production, standing out with a high proportion of commercial cuts with high quality meat. Thus this type of non-linear multiple regression equations developed in the present research is recommended, which suggests that one ultrasound measurement might be used next to the body weight to estimate carcass meat content and to improve the evaluation of the Carpatina kids earlier in their lifetime. All these objectives improved the characteristics necessary for the meat market classification of Carpatina goats with an appropriate and suitable meat production system. In this way carcass quality is ensured with the optimum weight and the amount of muscle and fat tissue, in the meat composition facilitating the chilling process and improving the taste and the organoleptic properties very well appreciated by consumers. Further investigations need to be conducted and confirm the findings on a significant number of animals with the best non-linear multiple regression equations fitted to provide a better evaluation in the selection of Carpatina kids for quality meat production.

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