**Research Article**

# Assessment of Growth Performance, Ultrasound Measurements, Carcass Merits and Meat Quality of Barki Lambs at Different Weaning Weights

**Zayed M.A[1], M.F. Shehata[1], I.M. Ismail[1], Mona Mohammady[1], M.A. Radwan[2*]**

*[1]Division of Animal and Poultry Production, Desert Research Center, Cairo, Egypt; [2]Department of Animal Production, Faculty of Agriculture, Cairo University, Giza, Egypt.*

**Abstract** | Weaning weight is considered one of pre-weaning traits which influence the post-weaning growth performance. In addition, ultrasound technique is commonly used in the livestock sector, such as a diagnostic tool and a tool in animal science and veterinary research. So, the present study was performed to study the effect of different weaning weights on growth performance, ultrasound measurements, carcass characteristics and meat quality of Barki ram-lambs. Moreover, this investigation aimed to examine the relationship among ultrasound measurements, body measurements, carcass characteristics and meat quality of Barki lambs. Twenty-three Barki lambs were divided into three groups according to their weaning weights: seven lambs in a low weaning weight group (G1), nine lambs in a medium weaning weight group (G2), seven lambs in a high weaning weight group (G3) (17.5±1.1, 22.7±1.0 and 28.4±1.1 kg, respectively), and raised for around seven months in an individual housing system. Subcutaneous fat thickness, muscle depth, muscle width, and muscle area at the 12$^{th}$ thoracic vertebrae were measured two times using the ultrasound scan. Body weight and measurements were recorded. All Barki lambs were slaughtered (one year of age approximately), and their carcass traits, and meat quality were evaluated. All growth performance traits showed significant ($p$<0.01) differences among the three groups, except birth weight and age. Dressing % (based on slaughter body weight) was higher ($p$ <0.05) in G3 than G1 and G2 groups. The lowest ($p$ <0.05) percentage of offal's was observed in G3 compared to G1 and G2 groups. Meat protein % was higher ($p$ <0.05) in G3 than G1 group. Meat of the G3 group was less ($p$ <0.05) tender than other two groups. The ultrasound *Longissimus dorsi* muscle area (ULDMA) and ultrasound fat thickness have a positive significant ($p$ <0.05) correlation with carcass back fat and carcass *Longissimus dorsi* muscle area. The hot carcass weight could be predicted using the ULDMA and slaughter body weight, where the model $R^2$ reached 95%. Our results confirmed that the weaning weight has an influence on the post-weaning growth traits, carcass merits and some meat quality parameters. Also the obtained results clearly indicated that the ultrasound technique could be used for the accurate prediction of carcass characteristics in Barki lambs.

**Keywords** | Barki sheep, Weaning weight, Ultrasound measurements, Meat quality, Carcass predict.

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***Correspondence** | M. A. Radwan, Department of Animal Production, Faculty of Agriculture, Cairo University, Giza, Egypt; **Email**: m.radwan883@agr.cu.edu.eg
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## INTRODUCTION

Barki sheep is one of the indigenous breeds that raise in the desert of the coastal zone of the Mediterranean Sea, which extends from west of Alexandria Governorate, Egypt to the eastern territories in Libya (Elshazly and Youngs, 2019; Abousoliman et al., 2020). This breed is characterized by small to medium body weight with small fat tail.

Weaning weight may be contributed to the selection criteria in a breeding program (Mousa et al., 2013). Selaive-Villarroel et al. (2008) reported that weaning weight has the important effect on post-weaning growth rate than weaning age and it has a positive impact on post-weaning body weight. In addition, slaughter body weight is affected on carcass characteristics and meat quality (Cañeque et al., 2001). The weaning weight of Barki sheep was ranged from 7.5 to 33 kg (Ibrahim et al., 2015; Sallam et al., 2019; Abousoliman et al., 2021). Ko et al. (2015), reported that weaning age and weight were not less significant than post-weaning growth traits and also effected on carcass traits and meat quality.

In the last decade, the demand for lean meat became greater than before in many countries around the world (Grill et al., 2015), and breeding studies have been motivated to changing carcass composition according to this demand (Yılmaz et al., 2014). Animal breeders have not only had to grow meat yield, but also produce lean meat to meet consumer demand. Previously, livestock breeding was based on the assessment of carcass composition, carcass grading and meat yield, which is usually done after slaughtering, which is considered costly (Akdag et al., 2015). Therefore, the assessment of carcass characteristics before slaughtering could be used to maximize resources exploitation and improve meat productivity (Moro et al., 2019). One of the methods that used for that purpose is ultrasound technique which could determine the quantity and quality of sheep meat (Agamy et al., 2015). However, in order to supply the increasing demands of both consumers and breeders, the use of a quicker, more efficient, and objective method such as ultrasound is becoming more common (Akdag et al., 2015, Leeds et al., 2008). Moreover, the ultrasound technique is commonly used in breeding programs for improving meat quality; where this technology is applied to identify meat quality parameters (Yılmaz et al., 2014). The technique of ultrasound is a noninvasive applied to ascertain carcass characteristics and composition depending on the depth, width, and area of the *Longissimus dorsi* muscle, in addition to the subcutaneous fat thickness around the muscle (Ripoll et al., 2009; Agamy et al., 2015). It is comparatively challenging to get ultrasound dimensions in sheep because of the silky and loose outer layer of subcutaneous fat and the wool (Leeds et al., 2008; Teixeira et al., 2006).

Szencziová and Strapák (2012), reported that ultrasound technique is commonly used in the livestock sector, such as a diagnostic tool and a tool in animal science and veterinary research. Noteworthy, the ultrasound technique is a better selection decision for end-product quality when applied in evaluation and prediction of body composition traits (FAO. 2012). Some animals may exhibit a unique combination of meat quality characteristics and considered a selected candidate for the herd germplasm (Buczinski, 2016). On the other hand, inferior animals for carcass quality could be identified are culled shortly after ultrasound scanning rather than having to wait for a progeny performance evaluation (Tait, 2016). The accuracy of ultrasound measurements is directly affected by the animal's age, sex, breed, and live weight, along with the ultrasound device used and the user's experience (Gökdal et al., 2004). Therefore, the present study was performed to study the effect of different weaning weight on growth performance, ultrasound measurements, carcass characteristics and meat quality of Barki lambs. Moreover, this investigation aimed to examine the relationship among ultrasound measurements, body measurements, carcass characteristics and meat quality of Barki ram-lambs.

## MATERIALS AND METHODS

The present study was conducted at Maryout Research Station, Desert Research Center, Ministry of Agriculture and Land Reclamation, the station is located 35 km south of Alexandria governorate, Egypt.

### Experimental procedures

Twenty-three Barki ram-lambs aged five months were used in the present study. All lambs were born in the same period (April). Experimental lambs were divided into three groups according to their weaning body weight. The groups were: seven lambs in low weaning weight group (G1) with an average body weight of 17.5 ± 1.1 kg, nine lambs in medium weaning weight group (G2) with an average body weight of 22.7 ± 1.0 kg and seven lambs in high weaning weight group (G3) with an average body weight of 28.4 ± 1.1 kg. All lambs were kept in an individual housing system. Lambs were fed certain amounts of commercial concentrate mixture (12% crude protein) plus alfalfa hay (*Trifolium alexandrinum*) which offered *ad libitum,* as well as drinking water. Moreover, the concentrate amounts were bi-weekly adjusted according to the live body weight change. Lambs were fed as per the standard schedule (NRC, 2007) to cover their nutritional requirements.

Ultrasound measurements in terms of *Longissimus dorsi* (*LD)* muscle width, depth and area were performed two times (eight months of age and prior to slaughter) with a portable ultrasound device (Imago ultrasound scanner with a 3.5-MHz) linear transducer. The back wool of the left side was sheared at $12^{th}$ rib and gel was placed before conducting the measurement to get a clear image according to Orman et al. (2010) and Akdag et al. (2015).

### Slaughtering, carcass measurements and meat quality analysis

At the end of the experiment (after 191 days), twenty-three ram-lambs were slaughtered following the standard protocol (Frild et al., 1963). Carcass traits were recorded, including empty body weight "EBW" (slaughter weight – digestive tract contents), hot carcass weight (HCW), cold carcass weight "CCW" (after 24h at 4-5 °C), Dressing percentage (based on SBW and EBW), wholesale cuts (Neck, shoulder, rack, loin, flank, leg, and tail) according to Islam et al. (2010), and edible parts (liver, heart, and kidneys) weights.

Chemical and physical analyses of meat were conducted at Cairo University Research Park (CURP), where the chemical composition was determined by a meat analyzer (FOSS, Denmark). The analysis outputs were moisture, protein collagen, and fat percentage. Physical traits included color, water-holding capacity (WHC), pH, and shear force. Meat color was evaluated using Chroma meter (Konica Minolta, model CR 410, Japan). Color, WHC percentage and the shear force (kg) were evaluated according to Farghaly et al. (2022).

### Statistical analysis

Data was analyzed by SAS® On Demand for Academics and it was subjected to one-way analysis of variance (ANOVA) using a general linear model (GLM). With weaning weight as the main effect as follows: $Y_{ij}$= +$G_i$+$e_{ij}$. Where: $Y_{ij}$ = the observation, = the overall mean, $G_j$ = the effect due to i^th weaning weight (Three levels; 1= low weaning weight (G1), 2= medium weaning weight (G2), and 3= high weaning weight (G3); $e_{ij}$ = random error associated with the $_{ij}$ observation. The significant differences were tested by Duncan. The Pearson correlation coefficients were determined among ultrasound, body, and carcass measurements. Regression analysis was used to establish estimation equations to predict hot carcass weight (HCW). The accuracy of the prediction was evaluated by the determination coefficient ($R^2$).

## RESULTS

### Growth performance

The least square means (LSM) of birth weight, weaning weight, slaughter body weight (SBW), gain, average daily gain (ADG) and age of three groups were presented in Table (1). All growth performance traits showed significant differences among the three groups ($p < 0.05$), except birth weight and age. Where the G3 had higher values compared with other groups. The growth curve of the three groups was shown in Figure (1).

### Body measurements

Live body measurements including body length, body circumference, body height and leg circumference of the three experimental groups shows in Table (2). Significant differences have existed among the three groups, wherever the G3 had the highest recorded compared with the other two groups ($p< 0.05$).

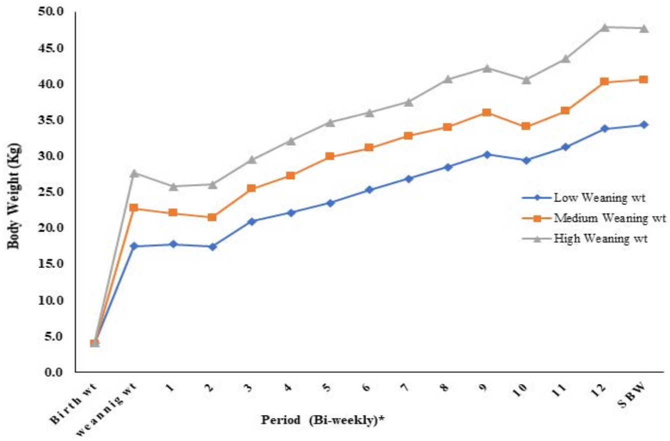


**Figure 1:** Growth curve of Barki lambs at different weaning weight: low, medium, and high weaning weight included birth weight.
SBW: Slaughter Body weight.
* Weighting was conducted bi-weekly except from birth weight to start fattening and from last weight to SBW.

### Ultrasound and real *Longissimus dorsi* measurements

Figure (2) shows the different ultrasound images of the three groups. While Table (3) presented the ultrasound and real *LD* muscle measurements in terms of back thickness (cm), *LD* width and *LD* depth of the three groups at eight months of age and prior to slaughter. Upon the different measurements that were conducted either than on live animals or on carcass had taken the same trend. In addition, the results showed significant differences ($p < 0.05$) among the three studied groups, except for the *LD* width.

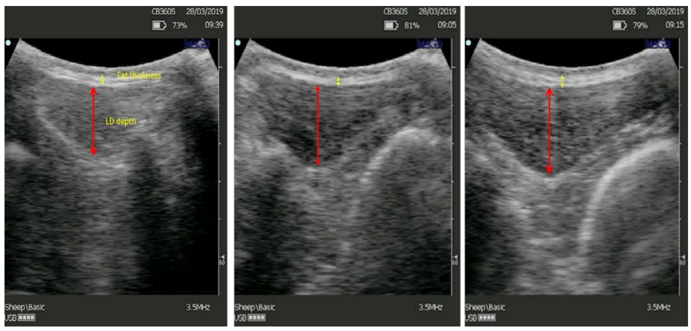

**Figure 2:** Ultrasound image of *Longissimus dorsi* (LD) muscle at 12th rib of Barki lambs at low, medium, and high weaning weight groups. (Images from left to right reflect Low to High weaning weight groups)

### Carcass measurements

Carcass measurements, including carcass length, Width at rib 3, carcass circumference, loin width, and leg circumference were shown in Table (4). Carcass length and width

**Table 1:** Least square means± standard error (LSM±SE) of growth traits of Barki lambs under the studied different weaning weights.

| Item | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|
| Birth weight (kg) | 3.99±0.1 | 3.88±0.1 | 4.05±0.1 | 0.594 |
| Weaning body weight (kg) | 17.5[c]±1.1 | 22.7[b] ±1.0 | 28.4[a] ±1.1 | <0.0001 |
| Slaughter body weight (kg) | 34.24[c]±1.1 | 40.57[b]±0.9 | 48.30[a]±1.1 | <0.0001 |
| Gain (kg) pre-weaning | 13.51[c]±1.5 | 18.82[b]±1.5 | 24.35[a]±1.5 | <0.001 |
| ADG (g) pre-weaning | 90.07[c] ±9.9 | 125.47[b]±10.5 | 162.33[a]±9.9 | <0.0001 |
| Gain (kg) Fattening period | 16.74[b]±0.7 | 17.87[b]±0.6 | 19.90[a]±0.7 | 0.006 |
| ADG (g) Fattening period | 87.64[b] ±3.7 | 93.56[b]±3.3 | 104.19[a]±3.7 | 0.006 |
| Age (days) | 349±3.5 | 353±3.1 | 358±3.5 | 0.19 |
| ADG (g) lifetime | 86.67[c] ±2.9 | 103.94[b]±2.6 | 123.60[a]±2.9 | <0.0001 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight.
LSM, within row with, different superscripts are significantly different (*P* <0.05).
ADG: Average daily gain.

**Table 2:** Least square means± standard error (LSM±SE) of live body measurements of Barki lambs under the studied different weaning weights.

| Item | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|
| Body Length | 74.71[b]±1.5 | 81.33[a]±1.3 | 84.57[a]±1.5 | 0.0004 |
| Body Circumference | 96.71[b]±2.6 | 103.78[ab]±2.3 | 110.43[a]±2.6 | 0.006 |
| Body Height | 70.14[b]±1.8 | 75.67[ab]±1.6 | 81.29[a]±1.8 | 0.001 |
| Leg Circumference | 48.86[c]±1.1 | 52.22[b]±1.0 | 56.00[a]±1.1 | 0.0006 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight.
LSM, within row with, different superscripts are significantly different (*P* <0.05).

**Table 3:** Least square means± standard error (LSM±SE) of ultrasound measurements and real *Longissimus dorsi* muscle area of Barki lambs under the studied different weaning weights.

| Item | time | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|---|
| **Conducted on live animal by ultrasound** | | | | | |
| Back thickness (cm) | At eight months of age | 0.33[c]±0.01 | 0.36[b]±0.01 | 0.41[a] ±0.01 | <0.0001 |
| ***LD* width (cm)** | | 4.0±0.2 | 4.2±0.1 | 4.3±0.2 | 0.52 |
| ***LD* depth (cm)** | | 1.9[b]±0.1 | 2.0[b]±0.1 | 2.3[a]±0.1 | 0.021 |
| ***LD* area (cm²)** | | 13.8[b]±0.6 | 14.6[b]±0.6 | 16.7[a]±0.6 | 0.021 |
| Back thickness (cm) | Prior to slaughter | 0.40[b]±0.01 | 0.43[b]±0.01 | 0.48[a] ±0.02 | 0.003 |
| ***LD* width (cm)** | | 4.9±0.2 | 5.07±0.2 | 5.15±0.2 | 0.697 |
| ***LD* depth(cm)** | | 2.1[b]±0.1 | 2.2[b]±0.1 | 2.5[a]±0.1 | 0.026 |
| ***LD* area (cm²)** | | 15.48[b]±0.6 | 16.23[ab]±0.5 | 17.96[a]±0.6 | 0.026 |
| Conducted on carcass | | | | | |
| Back thickness (cm) | After slaughtering | 0.32[c] ±0.02 | 0.37[b] ±0.01 | 0.60[a] ±0.02 | <0.0001 |
| **Real *LD* area (cm²)** | | 16.16[b]±0.75 | 17.78[b]±0.66 | 20.94[a]±0.75 | 0.001 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight. LD: *Longissimus dorsi.*
LSM, within row with, different superscripts are significantly different (*P* <0.05).

at rib 3 were higher in G2 and G3 compared to G1 ($p < 0.05$), as opposed result of the leg circumference. Also, carcass circumference showed the highest value in the G3 then G2 and G1. While the loin width was not influenced by weaning weight.

### Carcass characteristics

Carcass characteristics including EBW, HCW, cold carcass weight (CCW), chilling loss, dressing percentage (calculated based on SBW and EBW), edible organs, and total carcass fat of the three groups are presented in Table (5). Whereas the results of EBW, HCW, and CCW had the


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**Table 4:** Least square means± standard error (LSM±SE) of carcass measurements of Barki lambs under the studied different weaning weights.

| Item | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|
| Carcass length | 52.00$^{b}$±1.1 | 57.22$^{a}$±1.0 | 58.7$^{a}$±1.1 | 0.0008 |
| Width at rib 3 | 32.71$^{b}$±0.7 | 35.22$^{a}$±0.6 | 36.86$^{a}$±0.7 | 0.001 |
| Carcass circumference | 71.86$^{c}$±1.1 | 77.11$^{b}$±1.0 | 81.29$^{a}$±1.1 | <0.0001 |
| Loin width | 9.57±0.6 | 10.67±0.6 | 11.43±0.6 | 0.127 |
| Leg circumference | 33.71$^{b}$±1.2 | 33.56$^{b}$±1.0 | 36.00$^{a}$±1.1 | 0.008 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight.
LSM, within row with, different superscripts are significantly different (*P* <0.05).

**Table 5:** Least square means± standard error (LSM±SE) of Carcass characteristics of Barki lambs under the studied different weaning weights.

| Item | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|
| EBW (kg) | 29.84$^{c}$ ±1.0 | 35.11$^{b}$±0.9 | 41.63$^{a}$±1.0 | <0.0001 |
| HCW (kg) | 16.04$^{c}$ ±0.6 | 19.14$^{b}$±0.5 | 23.27$^{a}$±0.6 | <0.0001 |
| CCW (kg) | 15.72$^{c}$±0.5 | 18.81$^{b}$±0.5 | 22.67$^{a}$±0.5 | <0.0001 |
| Chilling loss % | 2.45±0.4 | 1.95±0.3 | 2.70±0.4 | 0.35 |
| Dressing % [1] | 46.81$^{b}$±0.6 | 47.22$^{b}$±0.5 | 49.19$^{a}$±0.6 | 0.019 |
| Dressing % [2] | 53.74$^{b}$±0.7 | 54.56$^{ab}$±0.6 | 55.92$^{a}$±0.7 | 0.1 |
| All offal's % [1] | 53.2$^{a}$±0.6 | 52.8$^{a}$±0.5 | 50.8$^{b}$±0.6 | 0.02 |
| Total fat % [1] | 2.8±0.2 | 2.7±0.2 | 3.4±0.3 | 0.2 |
| Non-carcass fat % [1] | 1.2±0.2 | 1.1±0.2 | 1.5±0.2 | 0.3 |
| Edible parts % [2] | 12.35±0.38 | 11.61±0.34 | 11.70±0.38 | 0.3 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight.
[1] were calculated based on slaughter body weight
[2] was calculated based on Empty body weight
Edible parts weight = Liver, Heart and Kidneys weights. EBW: Empty Body Weight = slaughter weight – digestive tract contents. HCW: Hot Carcass Weight. CCW: Cold Carcass Weight.
LSM, within row with, different superscripts are significantly different (*P* <0.05).

**Table 6:** Least square means± standard error (LSM±SE) of wholesale cuts percentage of cold carcass weight of Barki lambs under the studied different weaning weights.

| Item | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|
| Neck | 6.38±0.1 | 6.41±0.1 | 6.71±0.1 | 0.15 |
| Shoulder | 17.35±0.2 | 18.00±0.2 | 18.1±0.2 | 0.08 |
| Rack | 28.01$^{a}$ ±0.5 | 26.37$^{b}$±0.5 | 26.83$^{b}$±0.5 | 0.018 |
| Loin | 9.78±0.3 | 10.00±0.2 | 10.28±0.3 | 0.44 |
| Flank | 5.24$^{a}$±0.2 | 4.54$^{b}$±0.2 | 3.80$^{c}$±0.2 | 0.001 |
| Leg | 29.41$^{b}$±0.7 | 30.94$^{a}$±0.6 | 30.70$^{a}$±0.7 | 0.03 |
| Tail | 3.83±0.3 | 3.74±0.2 | 3.58±0.3 | 0.77 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight.
LSM, within row with, different superscripts are significantly different (*P* <0.05).

same pattern, which showed significant differences among the three studied groups. Furthermore, the dressing percentage (based on SBW or EBW) recorded the highest value in the G3 group compared to the two other groups. On the contrary, the offals percentage was higher in G1 and G2 groups than in the G3 group. While total fat, non-carcass fat, and edible parts percentages didn't appear any significant differences among three groups.

### Wholesale cuts

The LSM of wholesale cuts including neck, shoulder, rack, loin, flank, leg, and tail of the three groups are presented as percentages from cold carcass weight (Table 6). Significant differences have existed between the G1 and the other two

**Table 7:** Least square means± standard error (LSM±SE) of meat quality of Barki lambs under the studied different weaning weights.

| Item | G1 (LSM±SE) | G2 (LSM±SE) | G3 (LSM±SE) | P value |
|---|---|---|---|---|
| **Chemical composition** | | | | |
| Moisture | 72.39±0.4 | 72.76±0.3 | 72.59±0.4 | 0.9 |
| Protein | $19.85^{b}$±0.1 | $20.35^{ab}$±0.1 | $20.66^{a}$±0.1 | 0.03 |
| Fat | 5.30±0.5 | 5.31±0.3 | 5.92±0.5 | 0.8 |
| Collagen | $1.36^{a}$±0.04 | $1.22^{b}$±0.03 | $1.44^{a}$ ±0.05 | 0.009 |
| Physical properties | | | | |
| pH0 | $6.0^{b}$±0.1 | $6.2^{a}$±0.1 | $6.2^{a}$±0.1 | 0.02 |
| Ultimate pH | 5.6±0.1 | 5.6±0.1 | 5.5±0.1 | 0.86 |
| WHC | 69.6±2.6 | 65.6±2.6 | 68.1±2.6 | 0.16 |
| Shear Force (kgf/cm) | $6.2^{b}$±0.3 | $6.3^{b}$±0.2 | $7.1^{a}$±0.3 | 0.02 |
| Color | | | | |
| Lightness (L*) | 40.2±0.7 | 39.0±0.5 | 39.8±0.8 | 0.47 |
| Redness (a*) | 16.4±0.3 | 16.9±0.2 | 17.6±0.4 | 0.84 |
| Yellowness (b*) | 4.3±0.6 | 3.9±0.5 | 3.5±0.7 | 0.96 |
| Chroma | 16.8±0.4 | 17.5±0.3 | 17.7±0.4 | 0.55 |
| Hue | 11.7±1.1 | 12.7±0.9 | 10.9±1.1 | 0.12 |

G1: Low weaning weight, G2: Medium weaning weight, G3: High weaning weight.
LSM, within row with, different superscripts are significantly different (*P* <0.05).

**Table 8:** Correlation coefficients among ultrasound parameters and body measurements in addition to carcass characteristics.

| Variables | CBF | CLD-MA | UFT | ULD-MA | LBL | LBC | LBH | LLC | CL | Width R3 | CC | CLC | WADG | ADG | SBW | HCW | DP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CLDMA** | $0.67^{***}$ | | | | | | | | | | | | | | | | |
| UFT | $0.55^{**}$ | $0.65^{***}$ | | | | | | | | | | | | | | | |
| ULDMA | $0.53^{**}$ | $0.52^{*}$ | $0.5^{*}$ | | | | | | | | | | | | | | |
| LBL | $0.62^{**}$ | $0.54^{**}$ | $0.59^{**}$ | $0.6^{**}$ | | | | | | | | | | | | | |
| LBC | $0.57^{**}$ | $0.66^{***}$ | $0.44^{*}$ | $0.32^{ns}$ | $0.62^{**}$ | | | | | | | | | | | | |
| LBH | $0.71^{***}$ | $0.65^{***}$ | $0.43^{*}$ | $0.41^{ns}$ | $0.67^{***}$ | $0.79^{***}$ | | | | | | | | | | | |
| LLC | $0.58^{**}$ | $0.68^{***}$ | $0.57^{**}$ | $0.37^{ns}$ | $0.65^{***}$ | $0.66^{***}$ | $0.72^{***}$ | | | | | | | | | | |
| CL | $0.46^{*}$ | $0.22^{ns}$ | $0.43^{*}$ | $0.35^{ns}$ | $0.49^{*}$ | $0.37^{ns}$ | $0.29^{ns}$ | $0.43^{*}$ | | | | | | | | | |
| Width R3 | $0.6^{**}$ | $0.48^{*}$ | $0.57^{**}$ | $0.31^{ns}$ | $0.59^{**}$ | $0.46^{*}$ | $0.53^{**}$ | $0.42^{*}$ | $0.53^{**}$ | | | | | | | | |
| CC | $0.72^{***}$ | $0.64^{**}$ | $0.64^{**}$ | $0.38^{ns}$ | $0.61^{**}$ | $0.63^{**}$ | $0.69^{***}$ | $0.53^{**}$ | $0.52^{*}$ | $0.81^{***}$ | | | | | | | |
| CLC | $0.49^{*}$ | $0.7^{***}$ | $0.44^{*}$ | $0.28^{ns}$ | $0.36^{ns}$ | $0.46^{*}$ | $0.5^{*}$ | $0.66^{***}$ | $0.12^{ns}$ | $0.22^{ns}$ | $0.47^{*}$ | | | | | | |
| WADG | $0.83^{***}$ | $0.77^{***}$ | $0.65^{***}$ | $0.52^{*}$ | $0.67^{***}$ | $0.74^{***}$ | $0.82^{***}$ | $0.67^{***}$ | $0.56^{**}$ | $0.77^{***}$ | $0.91^{***}$ | $0.55^{**}$ | | | | | |
| ADG | $0.57^{**}$ | $0.45^{*}$ | $0.47^{*}$ | $0.31^{ns}$ | $0.31^{ns}$ | $0.58^{**}$ | $0.45^{*}$ | $0.26^{ns}$ | $0.46^{*}$ | $0.52^{*}$ | $0.73^{***}$ | $0.39^{ns}$ | $0.7^{***}$ | | | | |
| SBW | $0.85^{***}$ | $0.71^{***}$ | $0.63^{**}$ | $0.58^{**}$ | $0.78^{***}$ | $0.75^{***}$ | $0.86^{***}$ | $0.67^{***}$ | $0.58^{**}$ | $0.79^{***}$ | $0.88^{***}$ | $0.44^{*}$ | $0.97^{***}$ | $0.65^{***}$ | | | |
| HCW | $0.87^{***}$ | $0.74^{***}$ | $0.68^{***}$ | $0.59^{**}$ | $0.74^{***}$ | $0.65^{***}$ | $0.83^{***}$ | $0.69^{***}$ | $0.55^{**}$ | $0.78^{***}$ | $0.89^{***}$ | $0.49^{*}$ | $0.97^{***}$ | $0.61^{**}$ | $0.98^{***}$ | | |
| DP | $0.53^{**}$ | $0.51^{*}$ | $0.6^{**}$ | $0.36^{ns}$ | $0.26^{ns}$ | $-0.02^{ns}$ | $0.31^{ns}$ | $0.46^{*}$ | $0.21^{ns}$ | $0.43^{*}$ | $0.56^{**}$ | $0.46^{*}$ | $0.54^{**}$ | $0.25^{ns}$ | $0.47^{*}$ | $0.64^{**}$ | |
| Tfat | $0.37^{ns}$ | $0.48^{*}$ | $0.48^{*}$ | $0.31^{ns}$ | $0.18^{ns}$ | $-0.01^{ns}$ | $0.18^{ns}$ | $0.25^{ns}$ | $0.14^{ns}$ | $0.24^{ns}$ | $0.4^{ns}$ | $0.24^{ns}$ | $0.3^{ns}$ | $0.3^{ns}$ | $0.2^{ns}$ | $0.3^{ns}$ | $0.7^{**}$ |

CBF: carcass back fat, *CLD*MA: carcass *Longissimus dorsi* muscle area, UFT: Ultrasound fat thickness, *ULD*MA: Ultrasound *Longissimus dorsi* muscle area, LBL: live body length, LBC: live body circumference, LBH: live body height, LLC: Live leg circumference, CL: carcass length, Width R3: Width at rib 3, CC: Carcass circumference, CLC: carcass leg circumference, WADG: whole average daily gain, ADG: whole average daily gain, SBW: slaughter body weight, HCW: hot carcass weight and Tfat: Total fat. ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

groups according to rack and leg % ($p < 0.05$). The flank percentage was higher in G1 groups compared to G2 and G3 groups ($p < 0.05$). Even though no significant differences existed among the three studied groups on neck, shoulder, loin, and tail percentage.

## Meat quality traits

The LSM of meat quality as chemical composition (moisture, protein, fat, and collagen) and physical properties (pH0, ultimate pH, WHC, shear force, and color) were shown in Table (7). No significant differences have existed among the three diverse weaning weight groups on moisture, fat, ultimate pH, WHC, and color traits. However, the protein percentage was higher in the meat of the G3 compared with the G1 group. While the collagen percentage was lower in the G2 group compared with the other groups. The pH of meat after slaughtering and evisceration was lower in the G1 group compared with the G3 and G2 groups. The low shear force values were recognized in the G1 and G2 groups compared to the G3 group.

### Correlation coefficients among ultrasound estimates, body measurements, and carcass characteristics

Correlation coefficients among ultrasound parameters, body measurements and carcass characteristics are given in Table (8). There was a high positive significant correlation among some live body and carcass measurements with ultrasound measurements (area and fat thickness). The highest significant correlation coefficients were obtained between whole average daily gain (WADG) and both SBW and HCW (0.97). Whereas, the lowest significant correlation (0.43) was found between live leg circumference (LLC) and carcass length (CL), ultrasound fat thickness (UFT) and CL, and width R3 and dressing percentage (DP). In addition, UFT showed a positive significant correlation with carcass leg circumference (CLC), WADG, SBW and Total fat (Tfat) (0.57, 0.65 0.63, and 0.48; respectively). Interestingly, carcass back fat (CBF) had a highly positive significant correlation with live body height (LBH), CC, WADG, SBW and HCW (r = 0.71, 0.72, 0.83, 0.85 and 0.87, respectively). Moreover, CLDMA showed a highly positive significant correlation with LLC, CC, CLC, WADG, SBW and HCW (r = 0.68, 0.64, 0.70, 0.77, 0.71 and 0.74), respectively. However, CLDMA indicated a positive significant correlation with UFT, live body circumference (LBC) and LBH (r = 0.65, 0.66, and 0.65, respectively).

### Prediction equations of hot carcass weight using the ultrasound *Longissimus dorsi* muscle area (ULDMA)

The hot carcass weight (HCW) can be predicted using the ULDMA and SWB, where the model $R^2$ reached 95%.

## DISCUSSION

Birth weight, growth rate and weaning weight are considered pre-weaning traits (Akhtar et al., 2012) that could be affected post-weaning growth performance (Andrés et al., 2020). In present study, the birth weight and age of lambs were similar in three groups ($p$>0.05). But all growth performance traits were affected positively by weaning weight, where the gain and ADG at pre-weaning period, through whole age, weaning weight and SBW were significantly differ among three groups ($p$<0.05). Moreover, the gain and ADG from weaning to slaughter period were higher in G3 compared to G1 and G2 groups. These finding were agreed with Ghanem et al. (2022) and Selaive-Villarroel et al. (2008). Growth rate, weaning weight and slaughter weight are an important economic issue and expressed the production efficiency. So, these traits are considered in breeding programs (Shemeis, 2008). The growth curve of the three groups were taken the same trend (Figure 1), but differ regarding to different body gain, these outcomes were agreed with Singh et al. (2018).

In livestock markets, as tools to judge sheep is body measurements (Agamy, 2013), also using body measurements to predict carcass characteristics (Shehata, 2013a). In this study, all body measurements in terms of body length, body height, body circumference, and leg circumference values were increased by increasing the body weight, especially between G3 and G1 groups. These results agreed with the findings of Cam et al. (2010) and Agamy (2013), they found body weight and body measurements were positive correlated. Moreover, the carcass measurements had the same trend as body measurements except loin width which did not show any significant differences among three groups. These findings match with our results of the positive correlation between body and carcass measurements.
Ultrasonography technique is conducted on sheep farms to select the fit animals for slaughtering purpose and select the best animals to involve in a breeding program according to their carcass merits, that mains this technology will be applied widely due to low cost, less labor and quick application compared to traditional method (Gomes et al., 2021). Regarding to our findings, the *in vivo* ultrasound measurements, and real Longissimus dorsi (*LD*) muscle measurements on the carcass have a similar tendency. The back fat thickness, *LD* depth and *LD* muscle area were observed higher values in the G3 compared to G2 and G1, except the *LD* width ($p$>0.05), these results were matched with those of Agamy et al. (2015) and Silva (2017), they reported that there was a positive association with body weight. *LD* area was increases by increasing the body weight that agree with Abdel-Moneim et al. (2009), as well as back fat thickness which agree with Qadir et al. (2021).

In sheep the carcass weight and dressing percentage are key important tool to determine the carcass features for many actors along the meat chain. DP is very variated in small ruminants, ranged from 36% to 60% (Corazzin et al., 2019), this big variation due to numerous factors such as breed, age or slaughter weight, production system, and gender, but also on the slaughtering procedure, and whether it is calculated on the bases of full or empty body weight, which could be affected by rumen content (Assan 2015).

EBW, HCW and Cold carcass weight were higher in G3 group then G2 and G1 groups ($p$ <0.0001), that main it's a positive relationship between these variables and body weight which agrees with results of Ko et al. (2015) but in pigs. The average DP of Barki sheep with 12 months of age is ranged from 44.28 to 53.3% (Abdel-Moneim, 2009; Ibrahim et al., 2015; Shaaban et al., 2021). Also, the dressing percentage based on SBW was higher in the G3 group compared to G1 and G2 groups ($p$ <0.05), while DP based on EBW higher in G3 (55.92%) compared with G1 (53.74%) groups. These results disagree with Shehata (2013b) who found that the DP was higher in the medium body weight group compared to large and small body weight. The percentages of total fat, non-carcass fat based on SBW, and the edible parts based on EBW showed non-significant in the three groups under study but were not similar to the results of Shehata (2013b).

Wholesale cuts one of the indicators of growth performance, gain, carcass composition, consumers' preferences, and economics of meat production (Ahmed et al., 2022). Wholesale cuts the results of leg cut (prime cut) were higher in high weaning weight groups compared to low weaning group, but flank (low price cut) taken the opposite trend.

Chemical composition of meat is considerably linked with body weight and growth rate (Almeida et al., 2016) as well as breed, age and feeding system (de Lima Júnior et al., 2016). Protein % was higher in G3 (22.66%) than G1 (19.85%), could be linked growth rate with the same age, also the moisture and intramuscular fat were similar among three groups. Intramuscular fat was taken the same trend with tail %, total fat and non-carcass fat that main the most growth toward muscles. Share force test is applied to measure the maximum force that need to cut meat and it's referred to tenderness (Corazzin et al., 2019). Sarcomere length, proteolysis and collagen level are affected on meat tenderness which reported by Starkey et al. (2015). The group that recorded high weaning weight had higher shear force value (tougher) than medium and low weaning weight groups. This result could be associated with collagen level which was higher in G3 than G1 and G2 and this agrees with the result obtained by Starkey et al. (2015). Moreover, the enhancement of the body weight led to increased muscle fiber area (main more toughness) as reported by Argüello et al. (2005). Meat color is affected by numerous factors including animal age, farming practices (include diet), pre-slaughter (stress) and post harvesting that led to changes in myoglobin level and pH of meat (Prache et al., 2021). In our results, the meat color was similar among three groups ($p$>0.05), this could be due to the uniformity of age and conditions during the slaughter process.

According to results of correlation coefficients among ultrasound parameters, live body measurements and carcass characteristics, there was a high positive significant correlation between carcass *Longissimus dorsi* muscle area (CLDMA) with UFT and ULDMA (r = 0.65 and 0.52, respectively). The UFT presented a highly positive significant correlation ($p$ <0.001) with both carcass circumference (CC) and HCW (0.64 and 0.68), respectively. These current results agreed with those of Grill et al. (2015) who reported that correlations among ultrasonic and carcass measures varied from 0.60 to 0.84.

Generally, correlation coefficients were in the same range compared with previously published results such as Agamy et al. (2015), who reported that the body weight of Barki sheep had positive and significant correlations with the ultrasound backfat thickness and *Longissimus dorsi* muscle width r = 0.72 and 0.55, respectively. Similar results were obtained by Fernandez et al. (1997) who reported positive correlations between actual and ultrasound measurements (LD area, r = 0.88; and fat thickness, r=74) in Manchego, Merino, and Ile de France × Merino lambs. Also, Abdullah and Qudsieh (2008) noted an increase in carcass backfat thickness associated with the increase in the live weight of Awassi lambs (weight between 30-40 kg). On the other hand, carcass back fat thickness was not associated with the increase in the live weight of fat tailed Morkaraman lambs (weight between 40-45 kg).

Leeds et al. (2008) noted that a significant correlation coefficient was found (r = 0.77; $p$ < 0.01) between ultrasound fat thickness (UFT) and carcass fat thickness (CFT) in the Akkaraman lambs. While Romdhani and Djemali (2006) reported that the ultrasound and carcass fat thickness parameters were correlated (0.43) in Barbarine lambs, which is a fat-tailed breed. Understanding the previous results, which assumed that an increase in body weight initiates a significant increase in fat thickness (*in vivo* and carcass).

The HCW could be predicted using the ULDMA and SBW, the model $R^2$ = 95% through the following equation: HCW = -2.98+0.06*ULDMA+0.53*SBW. The obtained results clearly indicated that ultrasound technique could be used for the accurate prediction of carcass weight in Barki lambs in Egypt. This result was similar with the findings of Orman et al. (2010) who reported that it could be possible to develop a model to estimate the carcass fat amount (R2 = 75-88%) and carcass weight (R2 = 78-90%) using the UFT, ULDMA and body weight. Thereby, the ultrasound measurements could be applied for the accurate prediction of carcass components in Egyptian ram-lambs. The obtained prediction model is a helpful choice support implement to provide information on the perfect slaughter time to reach optimal values of carcass and edible tissues yield, which may cater the consumer preferences (Moro et al., 2019). Therefore, the previous data suggested that to select lambs for fattening purpose according to pre-weaning traits. Moreover, the hot carcass weight could be predicted by *Longissimus dorsi* muscle area measured by ultrasound and slaughter body weight.

## CONCLUSION

Our results confirmed that the weaning weight has an influence on the post-weaning growth traits, carcass merits and some meat quality parameters. Also, the obtained results show a strong and significant relationships between ultrasound measurements, both live body and carcass characteristics. The results of the current study documented the ability to predict carcass weight from live Barki lambs using the ultrasound technique. Therefore, this technique can be useful to accelerate the genetic progress of sheep meat production and quality.

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## CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

## AUTHORS CONTRIBUTION

All Authors participated in designing the experimental plan, collect data. Zayed, M.A, and Radwan, M.A. were participated in analyzing the samples, evaluated the results, and writing the manuscript. Shehata, M.F. Ismail, I.M., and Mohammady Mona were contributed to reviewing the manuscript. Radwan, M.A. was conducted statistical analysis, and publication of this paper.

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