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# EVALUATION OF BODY MEASUREMENTS OF LIMOUSIN HEIFERS BY BACKWARD REGRESSION ANALYSIS IN WESTERN HUNGARY

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## Abstract

Body measurements of yearling Limousin heifers (height at withers, HW, cm; tail height, HT, cm; back length, LB, cm; width at shoulders, WS, cm; hip bone width, WHB, cm; pin width, WP, cm) were taken in 7 nucleus farms in the Western Hungarian region n=322). The aim was to collect information on body sizes of yearling heifers and to work out regression equations for body measurements and live weight. Backward regression analyses and multifactorial regression analysis were completed using software SPSS 24.0.
Results of backward analysis revealed different $R^2$% values were obtained (49.2 - 92.5) for prediction of withers' height, tail height, length of back, and width of shoulders. Determination coefficients above 90% in cases of withers height and tail height imply that these parameters can be predicted by regression models accurately so one of them can be estimated. Both traits are useful in breeding-strategy for planning corrective matings.
For length of back and width at shoulders, precise prediction was not possible by these parameters. More researches are needed to find out better fitting models.
Live weight could not be estimated accurately enough ($R^2$=68.5 – 68.6%) from the available body measurements (withers height, tail height, length of back, width at shoulders, width at hip bones). Since other results imply that chest girth is strongly correlated with live weight, it is considerable for Hungarian Limousine breeders to involve this trait into measured parameters.
**Keywords:** body measurements, Limousin breed, heifers, backward regression analysis

## Összefoglalás

A szerzők egyéves kor körüli limousine üszők (n=322) testméreteit (marmagasság, cm; farmagasság, cm; háthosszúság, cm; vállszélesség, cm; csípőszélesség, cm; ülőgumók távolsága, cm) értékelték 7 nyugat-magyarországi törzstenyészetben. A testméreteket Limousin és Blonde d'Aquitaine Tenyésztők Egyesületének technikusa mérte, hagyományos eszközökkel (mérőbot, mérőszalag).
Cél volt az éves korú limousine üszők testméreteire vonatkozó adatgyűjtés, illetve regressziós függvények illesztése a testméretek~~re~~ és élősúly~~ra~~ kapcsolatára. Az adatokat backward

regresszióanalízissel, illetve többváltozós regresszió analízissel értékelték, az SPSS 24.0 szoftvert használva.
A backward analízis során különböző determinációs együtthatókat kaptak ($R^2$=49.2 – 92.5). A marmagasság és a farmagasság becslése során számított 90% feletti $R^2$ értékek arra utalnak, hogy ezen tulajdonságok valamelyike becsülhető lenne. Mindkét magassági méret ismerete szükséges a tenyésztői munkában a korrektív párosítások tervezéséhez.
A háthosszúság és a vállszélesség méretek a rendelkezésre álló adatokból nem voltak elég pontosan becsülhetők, további vizsgálatok lennének szükségesek jól illeszkedő modellek kidolgozásához.
Az élősúly becslése a mért testméretek alapján (marmagasság, farmagasság, háthosszúság, vállszélesség, farszélesség) nem volt pontos ($R^2$=68.5 – 68.6). Egyéb kutatási eredmények azt támasztják alá, hogy az övméret szorosan összefügg az élősúllyal, ezért elképzelhető, hogy a hazai tenyésztőknek is érdemes lenne bevonni a mért testméretek közé.
**Kulcsszavak:** testméretek, limousin üszők, backward regresszió analízis, többváltozós regresszió analízis

## Introduction

### Importance of body weight and measurements of beef cattle

Body weight is a crucial trait in livestock: it assists farm management processes in planning nutrition and vaccination, in marketing animals and when measuring growth performance, in decision of slaugter or breeding; and also, is a good indicator of condition (*Ulutas et al.,* 2002; *Bene et al.,* 2007; *Haq et al., 2020*).

Body measurements are also important parameters in beef cattle ~~sector~~ and can be used as selection criteria. At young ages they give information on the maturity of the animals, and also can be used to calculate indexes for the assessment of proportions of different body parts, as well as to estimate beef production (*Bene et al.,* 2007; *Ulutas et al.,* 2001; *Nogalski,* 2003; *Litwinczuk and Szulc,* 2005; *Przysucha et al.,* 2012). Heritabilities of body measures are comparatively high (0.37–8.88) (*Szabó*, 1998; *Arango et al*., 2002; *Bene et al*., 2007) resulting an efficient selection. Body measurements are often used in the prediction of body weight in different farm animal species (*Afolayan et al*., 2007; *Kashoma et al.*, 2011; *Mutua et al.*, 2011; *Yakubu et al*., 2015*; Tyasi et al.*, 2020) and are key indicators for the beef cattle fattening and breeding process (*Li et al.*, 2002).

### Methods of taking body measurements

Body measurement of beef cattle is often carried out by the traditional method, with the assistance of tape measures and measuring sticks, which usually takes around 3–5 min per animal (*Tőzsér et al*. 1995, *Ouédraogo et al*., 2020).

Since heart girth (chest circumference) is a measurement highly correlated with live weight, a measuring tape was developped, which contains the reference scale to find out the body weight of the animal (*Sales et al*., 2009; *Abreu et al.,* 2015). However, the tape requires direct human-animal contact so it may cause stress.

On-animal measurement can induce severe stress responses among beef cattle which affect well-being and thus, feed intake and growth of cattle; and can also be a risk for technicians (*Augspurger et al*., 2002; *Petherick et al*., 2009; *Li et al.,* 2022). To lessen stress

10.17205/SZIE.AWETH.2023.1.102

factors, modern digital methods have been developed for non-contact weight measurement that can be carried out by a two-dimensional CCD camera (*Kongsro et al*, 2014; *Shi et al*., 2016) or three-dimensional camera (*Wongshiworapon et al.*, 2015).

*Tőzsér et al.* (2000a) measured height at withers (HW) and chest depth (CD) of 16 suckler cows and 17 dairy cows using the traditional method and video image analysis (VIA). Image measurements were carried out manually. The mean HW and CD values for suckler cows were 132±4.78 and 74±5.98 cm by traditional measurement; while 129±5.35 and 75±5.58 cm by VIA, respectively. Relevant values (HW, CD) of dairy cows were 139±6.53 and 76±4.54 cm by traditional method, and 136±5.85 and 77±3.66 cm by VIA, respectively. Relative mean errors for suckler and dairy cows ranged between 0.90% - 2.02% and 1.04 - 1.46%, respectively. HW values measured by traditional method were significantly larger than VIA values for both groups of cows ($P$<0.05). CD values were independent from method of measurement ($P$>0.05). Significant positive correlations were obtained between traditional and VIA body measures (suckler cow, HW: r=0.77, $P$<0.001; CD: r=0.96, $P$<0.001; dairy cows, HW: r=0.86, $P$<0.001; CD: r=0.87, $P$<0.001) which implied that video can be used to measure HW and CD precisely in farm practice.

*Ozkaya et al.* (2015) reported body measurements taken by traditional and video image analysis methods and live weight results for adult Limousin cows (n=56) of different ages categories (*Table 1*). In comparison of the traditional and VIA body measurement results, the accuracy was 98% for withers height, 97% for hip height, 94% for chest depth and 90.6% for body length. Using regression analysis, $R^2$=61.5% was found when analysing regression between body surface and live weight. Regression equation including all VIA measurement traits had 88.7% reliability when estimating body weight. Despite the fact that the equipments and software for image processing have become cheaper, VIA method has not became widespread in the practice of taking cattle body measurements.

***Table 1*: Body measurements of Limousin cows (n=56) by traditional and VIA method**
(*Ozkaya* et al., 2015)

| **Parameter**(1) | **Traditional measurement**(2) | **VIA**(3) |
|---|---|---|
| Body weight, kg(4) | 616.7±21.3 | – |
| Withers height, cm(5) | 127.9±1.3 | 128.9±1.3 |
| Body length, cm(6) | 164.3±2.1 | 165.6±1.8 |
| Chest girth, cm(7) | 69.1±0.9 | 70.5±0.9 |
| Hip height, cm(8) | 132.9±1.3 | 133.8±1.3 |
| Body area, $cm^2$(9) | – | 17223±1371 |

*1. táblázat: Limousine tehenek testméretei hagyományos módszerrel és videokép-analízissel mérve (forrás: Ozkaya és mtsai, 2015)*
Tulajdonság(1); hagyományos módszerrel(2); videokép-analízissel(3); élősúly, kg(4); marmagasság(5); testhosszúság(6); mellkasmélység(7); csípőszélesség(8); testfelület, $cm^2$(9)

To eliminate most of the human labour, automatic methods were developed to measure cattle body dimensions. *Xu* (2022) marked the key points of the cattle body from RGB images through the CentreNet network, and extracted the core parameters like body length, oblique body length, and wither's height, based on the location of key points. *Weales et al.* (2021) divided cattle body area into three equal regions along the direction of the dorsal line, and the widest slice in each region from top view was recorded to extract the core parameters: wither's height, chest girth, and heart circumference. Average errors ranged form 1.9 to 2.3%. *Gritsenko et al.* (2023) also used RGB-D image capture system to measure the live weight of Holstein Friesian ~~mother~~ cows, as well as the live weight and body sizes (height at the withers, height in the sacrum, oblique length of the trunk, chest depth, chest girth, pastern girth) of their calves (altogether n=561). The system was based on a non-rigid 3D shape reconstruction using data gathered from 3 depth cameras. The measurements taken on generated 3D body models were compared with 9 references measured manually. With a 90% level of coincidence, the system had less than 3% errors. A machine learning model (*Ruchay*, 2022) was applied to predict the live weight: the model used body measurements and age of cattle. The accuracy of weight measurement using the model was 95.67%.

Although – based on geometric relationships - these methods enable automatic location and identification of body measurement points, the measurement results are easily influenced by the changeable postures and the differences in body shape which may result in high deviations from the real values. To avoid this, a measurement method was proposed, based on the distribution characteristics of reconstructed three-dimensional point cloud data. This method is able to extract the targeted point cloud regions automatically. In the experiment of *Li et al.* (2022), the horizontal continuous slice sequence of the complete point clouds was first extracted, then the central point of the beef cattle leg region was determined from the span distribution of the point cloud clusters in the targeted slices. After that, the boundary of leg region was identified by a "five-point clustering gradient boundary recognition algorithm" and was then calibrated, followed by the exact segmentation of the corresponding region. The key regions for body dimension data calculation were determined by the proposed algorithm, which formed as a basis for the calculation of key body dimensions. The errors of calculated oblique body length, withers height, chest width, abdominal girth, and chest girth, were 2.3%, 2.8%, 1.6%, 2.8%, and 2.6%, respectively; which implied that automatic method can be used to take body measurements of beef cattle reliably. Compared with the method that was based on the "point" features, this method, that focused on the "region" features, seemed to be more suitable to deal with incomplete point clouds and possessed limited requirements regarding animal postures.

**Prediction of live weight using body dimensions**

*Hlokoe and Tyasi* (2022) used body measurement traits (heart girth (HG), body weight (BW), rump width (RW), body length (BL), head length (HL), withers height (WH), ear length (EL), rump height (RH), head width (HW) and sternum height (SH)) for the prediction of body weight in Nguni cattle (59 cows, 11 bulls) aged 2-4 years. Pearson correlation and stepwise regression was applied for the analysis of data. Body weight correlated significantly closely ($P < 0.01$) with WH ($r = 0.94$), HG ($r = 0.91$), RH ($r = 0.88$), SH ($r = 0.90$), RW ($r = 0.73$) and also significant positive correlations ($P < 0.05$) were revealed with EL ($r = 0.47$), and BL ($r = 0.46$) in bulls. In case of cows, body weight had a positively high remarkable relationship ($P < 0.01$) with HG ($r = 0.75$), RH ($r = 0.69$) and WH ($r = 0.57$), and correlated with $P<0.05$ level of significance with BL ($r = 0.43$), SH ($r = 0.38$) and HW ($r = 0.28$). These correlations imply that enhancement of WH, HG, SH, RH, RW, EL, BL, and HW might improve BW of Nguni cattle. Results of stepwise regression indicated that the best fitting model for estimation of BW in bulls included WH, HG, SH, RH, RW, HL, EL, and BL ($R^2 = 0.95$, MSE = 817.51) while for cows, it contained HG, RH and WH ($R^2 = 0.62$, MSE = 4887.31). Regression models including different body measurements to estimate body weight are shown in *Table 2*.

10.17205/SZIE.AWETH.2023.1.102

***Table 2:* Regression models, determination coefficient and mean square error (MSE) for estimation of body weight Nguni cows** (Source: *Hlokoe and Tyasi, 2022*)

| Model(1) | $R^2$ | MSE(2) |
|---|---|---|
| BW = -310.19 + 3.64HG | 0.57 | 5278.80 |
| BW = -505.83 + 2.59HG + 3.00RH | 0.61 | 4935.20 |
| BW = -548.81 + 2.36HG + 2.52RH + 1.23WH | 0.62 | 4887.31 |
| BW = -555.49 + 2.32HG + 2.42RH + 1.20WH + 0.23BL | 0.62 | 4984.37 |
| BW = -488.92 + 2.45HG + 2.56RH + 1.24WH + 0.17BL – 1.55SH | 0.62 | 5058.92 |
| BW = -431.69 + 2.44HG + 2.65RH + 1.29WH + 0.20BL – 1.60SH - 3.24HW | 0.62 | 5168.73 |

*2. táblázat: Regressziós modellek nguni fajtájú tehenek élősúlyának becslésére (forrás: Hlokoe és Tyasi, 2022)*
Modell(1); átlagos négyzetes hiba(2)

*Udoh et al.* (2021) elaborated regression equations to predict body weight of White Funali and Muturu cows (n=25 per breed) from different body measurements. *Table 3*. introduces the obtained models.

***Table 3:* Linear regression equations to predict weight from linear body measurements in White Fulani and Muturu breeds** (Source: *Udoh et al*., 2021)

| Parameter(1) | Breed(2) | Regression equation(3) | r | $R^2$ |
|---|---|---|---|---|
| Body length (BL)(4) | White Fulani | BW= 422.12+2.554BL | 0.71 | 0.661 |
| | Muturu | BW= -298.15+3.893BL | 0.99 | 0.980 |
| Face lenght (FL)(5) | White Fulani | BW= 50.71+4.33FCL | 0.21 | 0.045 |
| | Muturu | BW= -185.65+8.182FCL | 0.88 | 0.775 |
| Head circumference (HC)(6) | White Fulani | BW= 136.71+1.44HC | 0.23 | 0.055 |
| | Muturu | BW= -222.199+5.14HC | 0.85 | 0.717 |
| Ear length (EL)(7) | White Fulani | BW= 512.77+-11.79EL | 0.42 | 0.177 |
| | Muturu | BW= -324.40+31.295EL | 0.77 | 0.587 |
| Neck circumference (NC)(8) | White Fulani | BW= 199.43+0.76NC | 0.15 | 0.022 |
| | Muturu | BW= -177.18+5.65NC | 0.86 | 0.734 |
| Withers' height (HW)(9) | White Fulani | BW= 62.59+1.48HW | 0.15 | 0.023 |
| | Muturu | BW= -116.396+2.76HW | 1.84 | 0.662 |
| Body circumference (BC)(10) | White Fulani | BW= 456.13+4.98BC | 0.89 | 0.787 |
| | Muturu | BW= -264.02+3.57BC | 0.99 | 0.980 |
| Fore limb length (FL)(11) | White Fulani | BW= 46.54+2.399FL | 0.29 | 0.089 |
| | Muturu | BW= -44.46+2.77FL | 0.39 | 0.153 |
| Hind limb length (HL)(12) | White Fulani | BW= 134.60+1.22HL | 0.15 | 0.021 |
| | Muturu | BW= -235.98+4.88HL | 0.85 | 0.725 |
| Tail length (TL)(13) | White Fulani | BW= 171.71+0.82TL | 0.31 | 0.094 |
| | Muturu | BW= 46.37+1.45TL | 0.44 | 0.195 |
| Neck length (NL)(14) | White Fulani | BW= 94.30+5.04NL | 0.39 | 0.153 |
| | Muturu | BW= -890.11+34.996NL | 0.91 | 0.829 |

*3. táblázat: Lineáris regressziós egyenletek a fehér fulani és muturu fajták élősúlyának becslésére különböző testméretek alapján. (Forrás: Udoh és mtsai, 2021)*
Paraméter(1); fajta(2); regressziós egyenlet(3); testhossz(4); pofa hossza(5); fejkörméret (6); fülhossz(7); nyakkörméret(8); marmagasság(9), mellkaskörméret(10); elülső láb hossza(11); hátulsó láb hossza(12); farokhossz(13); nyak hossza(14)

It is interesting to experience the large difference between breeds regarding the relations of different body dimensions and live weight. However, in both breeds body length and body circumference were the most accurate predictors of body weight.

*Haq et al.* (2020) created equations to predict body weight of Jabres cattle of different sexes and ages using body dimensions by multiple linear regression and factorial analysis scores followed by multiple linear regression methods. Results showed that multiple linear regression method was preferable to use due to its better accuracy, and fitness (*Table 4*). Also, it is easier applicable for farmers because they can use the cattle body size measurement result directly without needing to transform it first to an other form (i.e. factor).

***Table 4.* Linear regression model summary for body measurements of Jabres cattle with live weight as a dependent variable** (Source: *Haq et al*., 2020)

| **Parameter(1)** | **Cow/heifer(2)** | | **Bull(3)** | |
|---|---|---|---|---|
| | **< 1yr** | **≥1 yr** | **< 1yr** | **≥1 yr** |
| Constant(4) | -167.510 - | -263.129 | -146.489 | -326.336 |
| Variables(5) | | | | |
| Body length(6) | 1.405 | - | 0.873 | 2.178 |
| Heart girth(7) | 1.760 | 3.149 | 2.324 | 2,943 |
| Withers height(8) | 0.088 | -0.077 | - | - |
| Rump height(9) | -0.435 | 0.115 | -0.603 | -0.955 |
| Face length(10) | -0.187 | - | -0.292 | - |
| Face width(11) | - | - | -1.143 | -0.307 |
| Adjusted $R^2$(12) | 0,968 | 0,726 | 0,971 | 0,990 |
| Std. Error of Estimate(13) | 8,500 | 18.649 | 6,664 | 6,330 |
| RMSE(14) | 8.171 | 18.533 | 6.193 | 6.118 |
| Standard deviation ratio(15) | 0.174 | 0.521 | 0.161 | 0.099 |

4. *táblázat: Lineáris regressziós modellek a Jabres fajta élősúlyának becslésére a testméretek ismeretében (Forrás: Hau és mtsai, 2020)*

Paraméter(1); üsző=tehén(2); bika(3); állandó(4); változók(5); testhossz (6); övméret(7); marmagasság(8); farmagasság(9), pofa hossza(10); pofa szélessége(11); korrigált $R^2$(12); becslés standard hibája(13); átlagos négyzetes eltérés(14); szórás aránya(15)

*Terada et al.* (1993) used body measurements of Japanese Black (JB) and Holstein Friesian (HF) heifers (JB n=15; HF n=15) and cows (JB n=16; HF n=9) to estimate live body weight. Regression coefficients and determination coefficients are shown in *Table 5*.

10.17205/SZIE.AWETH.2023.1.102

***Table 5*: Results of regression analysis for prediction of body weight from body measures** (Source: *Terada et al*., 1993)

| **Item(1)** | **Japanese Black** | | **Holstein** | |
|---|---|---|---|---|
| | **heifer(2)** | **cow(3)** | **heifer(2)** | **cow(3)** |
| Hip height(4) | - | - | - | -0.165 |
| Body length(5) | 0.204 | 0.214 | - | - |
| Chest girth(6) | 0.707 | 0.755 | 0.497 | 0.371 |
| Chest depth(7) | - | -0.325 | - | - |
| Chest width(8) | - | 0.252 | 0.188 | 0.237 |
| Rump length(9) | - | -0.379 | | 0.394 |
| Hip width(10) | - | - | 0.345 | 0.474 |
| R2 | 0.856 | 0.924 | 0.965 | 0.971 |

5. *táblázat: Regresszió analízis eredményei japán fekete és holstein fríz szarvasmarhák testméretei alapján becsült élősúlyokra vonatkozóan (Forrás: Terada és mtsai, 1993)*
Paraméter(1); üsző(2); tehén(3); csípőmagasság(4); testhossz(5); övméret(6); mellkasmélység (7); mellkasszélesség(8); farszélesség(9), csípőszélesség(10)

Again, it is worth attention that in different breeds at different age groups, different parameters were involved in the estimation. What is common, that chest girth was among the most important factors in prediction of body in all cases. Other authors' results also support the strong correlation between weight and body length and chest circumference (=heart girth) in different cattle breeds (*Ni'am et al.* 2012; *Paputungan et al*. 2013; *Putra et al.* 2014; *Suliani et al.*, 2017; *Tebug et al*.,2018; *Ozkaya and Bozkurt*, 2009; *Ashwin et al.*, 2019).
The aim of present study was to gather information on body measurements of yearling Limuosine heifers in Hungary, to evaluate them by backward regression and to try to find a well-fitted model to predict live weight.

## Material and methods

A couple of years ago, Association of Hungarian Limousin Cattle Breeders has modified its breeding program and within the frames of modification body measurements of yearling Limousin heifers were taken in several nucleus farms in Hungary. Body measurements were taken by a skilled technician with standardized equipment under appropriate conditions (plain concrete floor, fixing animals in corridor). The methods of measurements are described in *Table 6*.

***Table 6:*** **Methods for taking body measurements**

| Body measurement (1) | Measuring points(2) | Equipment(3) |
|---|---|---|
| Withers height(4) | horizontal distance between the ground and the withers(10) | measuring stick(16) |
| Tail height(5) | horizontal distance between the ground and the hip bone(11) | measuring stick(16) |
| Length of back(6) | distance between the withers and the loin(12) | tape measure(17) |
| Width of shoulders(7) | width at the widest point of the withers(13) | measuring stick(16) |
| Width at hip bone(8) | distance between the two points of hip(14) | measuring stick(16) |
| Pin width(9) | distance between the two ischium(15) | measuring stick(16) |

6. *táblázat: A testméret felvételezés módja*
Testméret(1); mérési pontok(2); eszköz(3); marmagasság(4); farmagasság(5); háthosszúság(6); vállszélesség (7); csípőszélesség(8); ülőgumók távolsága(9), talaj és a mar legmagasabb pontja közti függőleges távolság(10); talaj és a csípőcsont közti függőleges távolság(11); mar és ágyék közti távolság(12); a mar legszélesebb pontjai közti távolság(13); csípőcsontok közti távolság(14); ülőgumók közti távolság(15); mérőbot(16); mérőszalag(17)

Data of nucleus farms from the Western part of Hungary (7 farms with heifers 9-70; n=322 altogether) were used in this evaluation.
SPSS 24.0 was used for statistical analysis: backward regression analyses and multifactorial regression analysis were completed.

**Results and discussion**

Mean values for age, weight and body measurements of Limousin heifers are presented in *Table 7*. Mature weight of an average Limousin cow is 600 kg – value of yearling heifers reached almost 70% of it (419.9 kg; 69.83%), implying an appropriate maturity of the age.

***Table 7:*** **Descriptive statistic data of Limousine heifers in Western Hungary (n=322)**

| **Parameters(1)** | **Mean(2)** | **Std. Deviation(3)** | **Std. Error Mean(4)** |
|---|---|---|---|
| Live weight, LW (kg)(5) | 419.94 | 74.468 | 4.150 |
| Age (days)(6) | 428.10 | 44.972 | 2.506 |
| Withers height, HW (cm)(7) | 120.19 | 6.027 | 0.336 |
| Tail height, HT (cm)(8) | 129.53 | 6.282 | 0.350 |
| Length of back, LB (cm)(9) | 71.36 | 5.282 | 0.294 |
| Width at shoulders, WS (cm)(10) | 31.43 | 3.474 | 0.194 |
| Width at hip bone, WHB (cm)(11) | 39.66 | 3.293 | 0.184 |
| Pin width, WP (cm)(12) | 15.45 | 1.138 | 0.063 |

7. *táblázat: Limousine üszők (n=322) leíró statisztikai adatai Nyugat-Magyarország régióban*
Paraméterek(1); átlagérték(2); szórás(3); átlag standard hibája(4); élősúly, kg(5); életkor, nap(6); marmagasság, cm (7); farmagasság, cm(8); háthosszúság, cm(9), vállszélesség, cm(10); csípőszélesség, cm(11); ülőgumók távolsága, cm(12)

Pearson correlations between body measurements are shown in *Table 8*. Significant positive correlations were observed in all relations. Naturally, very strong correlations were obtained for the two height parameters (r≥0.9), which supports the idea of estimating one of these measurements by a regression model. *Nagy* (2007), *Domokos* (2011), *Weber et al.* (2020), *Haq et al.* (2021) also observed close correlation (0.86) between withers' and hip height. In the same time, correlation values between width traits were intermediate (0.42 – 0.64). It has to be emphasized that all body measurements are important in selection of breeding animals, so they either have to be measured or estimated with high accuracy so that they can be used in corrective mating plans. Height at withers had the highest correlation to live weight (0.72). Surveying results of different researches, it was found that chest circumference was the body measurement that mostly related to live weight in different breeds and ages of cattle (*Tőzsér et al.*, 2000; *Nagy*, 2007; *Terada*, 1993; *Hloke and Tyasi*, 2022; *Udoh et al*. 2021, *Haq et al*. 2020; *Ni'am et al*. 2012; *Paputungan et al*. 2013; *Putra et al.* 2014; *Suliani et al.*, 2017; *Tebug et al*.,2018; *Ozkaya and Bozkurt*, 2009; *Ashwin et al.*, 2019), however it was not included among present measurements of Limousin heifers. Although measurement of this trait is more difficult by traditional method, it would be advisable to consider to involve it into the measured parameters. In Hungary, among beef breeds, researches were focused on body measurements of Charolais cows and heifers (*Tőzsér et al*., 2000; 2001), but not on Limousin so far. *Tőzsér et al.* (2020) revealed loose correlations between live weight and withers height (0.20), chest girth (r=0.39) and chest circumference (r=0.48) of weaned Charolais heifers in two Hungarian herds (n=20 and 21).

***Table 8*: Pearson correlations in Western Hungarian farms (n=332)**

| **Parameters(1)** | **Withers height WH (cm)(2)** | **LW (kg)(3)** | **AG (days)(4)** | **HT (cm)(5)** | **LB (cm)(6)** | **WS (cm)(7)** | **WHB (cm)(8)** |
|---|---|---|---|---|---|---|---|
| Live weight, LW (kg)(3) | 0.724*** | | | | | | |
| Age, AG (days)(4) | 0.437*** | 0.328*** | | | | | |
| Tail height, HT (cm)(5) | 0.959*** | 0.713*** | 0.408*** | | | | |
| Length of back, LB (cm)(6) | 0.609*** | 0.672*** | 0.270*** | 0.618*** | | | |
| Width of shoulders, WS (cm)(7) | 0.564*** | 0.582*** | 0.243*** | 0.564*** | 0.431*** | | |
| Width at hip bone, WHB (cm)(8) | 0.586*** | 0.620*** | 0.255*** | 0.590*** | 0.409*** | 0.642*** | |
| Pin width, WP (cm)(9) | 0.467*** | 0.566*** | 0.181*** | 0.460*** | 0.442*** | 0.454*** | 0.416*** |

***=P<0.001, **=P<0.01, *=P<0.05

8. *táblázat: A testméretek közti Pearson korrelációk a vizsgált limousine üszők esetén* Testméret(1); marmagasság, cm(2); élősúly, kg(3); kor, nap(4); farmagasság, cm(5); háthosszúság, cm(6); vállszélesség, cm (7); csípőszélesség, cm(8); ülőgumók távolsága, cm(9)

Outcomes of multifactorial regression analysis are presented in *Table 9*. $R^2$ values were between relatively large intervals (49% to 90%) – for height traits they were higher than for the two other traits. In case of withers and tail height, analysis consisted of 5 steps and 3-3 parameters were involved in the final models as independent variables. Withers height was predicted by live weight, age, and tail height ($R^2$=0.925); while tail height was estimated the best using withers height, length of back and width at hip bones ($R^2$=0.923).

**_Table 9_: Main results of the multifactorial regression analysis**

| **Method(1)** | **Backward regression analysis(2)** | | | |
|---|---|---|---|---|
| **Dependent variables, y(3)** | **$R^2$ (%)** | **Number of steps(8)** | **Number of predicators variables (x)(9)** | **Regression coefficients, b(10)** |
| Withers height, cm(4) | 92,5*** | 5 | 3 | LW:0.006***, AG:0.007**, HT:0.847*** |
| Tail height, cm(5) | 92,3*** | 5 | 3 | HW:0.944***, LB:0.060**, WHB:0.072* |
| Length of back, cm(6) | 49,5*** | 5 | 3 | LW:0.036***, HT:0.259***, WHB:-0.140 |
| Width of shoulders, cm(7) | 49,4*** | 4 | 4 | LW:0,006*,. HT:0.093**, WHB:0.426***:, WP:0.402** |

***=P<0.001, **=P<0.01, *=P<0.05

9. *táblázat: A többváltozós regresszió analízis eredményei*

Módszer(1); backward regresszió analízis(2); függő változók(3); marmagasság(4); farmagasság(5); háthosszúság(6); vállszélesség (7); lépések száma(8); becslésre használt változók száma(9), regressziós együttható, b(10)

Interestingly, the tail height, live weight and width at hip bones were involved in the estimation model of back length resulting an $R^2$ of 49.5%. Final model of width of shoulders after 4 steps consisted of live weight, tail height, width at hip bone and pin width, with a considerably low level of determination coefficient (0.494).

*Table 10* introduces the regression equations obtained by multifactorial regression analysis to predict live weight by different body measurements.

*Table 10*: **Estimation of live weight by the multifactorial regression analysis**

| **Models(1)** | **Backward regression analysis(2)** | | | |
|---|---|---|---|---|
| **Dependent variable, y(3)** | **$R^2$ (%)** | **Number of steps(4)** | **Number of predictor variables (x)(5)** | **Regression coefficients, b(6)** |
| Live weight, LW (kg)(7) | 68.6*** | 1 | 7 | AG:0.031, WH: 3.690*, HT:-0.079, LB:4.148***, WS:1,594, WHB:4.562***, WP:11.578*** |
| Live weight, LW (kg)(7) | 68.6*** | 2 | 6 | AG:0.032, WH: 3.615***, LB:4.148***, WS:1,592, WHB:4.557***, WP:11.580*** |
| Live weight, LW (kg)(7) | 68.5*** | 3 | 5 | WH: 3.718***, LB:4.183***, WS:1,592, WHB:4.560***, WP:11.539*** |

***=P<0.001, **=P<0.01, *=P<0.05

10. *táblázat: Az élősúly becslése többváltozós regresszió analízissel*

Modelleg(1); backward regresszió analízis(2); függő változó(3); lépések száma(4); független változók száma(5); regressziós együtthatók, b(6); élősúly (7)

All the three models estimated live weight with the same level of determination coefficient (68.5-68.6%) using different body dimensions. The first model contained 7; the second one 6 and the third one 5 parameters. Tail height and age were not involved in the third model. It seemed that live weight could not be estimated accurately enough from the available body measurements. Since other results support that chest girth is strongly correlated with live weight (*Tebug et al*., 2018; *Ozkaya and Bozkurt*, 2009; *Francis et al*., 2009; *Ashwin et al*., 2019; *Weber et al.*, 2020), it is worth considering for Hungarian Limousin breeders to involve this trait into measured parameters.

*Table 11* also summarizes results of some researches aiming the prediction of live weight using different body measurements. All of them support that several body measures, individually or together, influenced live weight significantly.

***Table 11*: Results of prediction live weight by different body measures in cattle breeds**

| Breeds and sexes(1) | Results(2) | Source(3) |
|---|---|---|
| Female dairy cattle, mainly comprising indigenous Zebu and their crosses with Guzerat or Bos Taurus(4) | The best model to predict LW from heart girth (HG) had adjusted $R^2$ of 0.85(5) | *Tebug et al.*, (2018) |
| Holstein, Brown Swiss and crossbred cattle(6) | Chest girth (CG) was the best parameter to predict body weight (Brown Swiss: $R^2$=91.1%; crossbred cattle: $R^2$=88.8%; Holstein: $R^2$=60.7%)(7) | *Ozkaya and Bozkurt* (2009): |
| Indigenous, Friesian, Brahman, Red Dane and Crossbred cattle(8) | LW was strongly correlated (r= 0.90) with body length, heart girth and height at withers. Correlation with HG was outstandingly strong (r = 0.96)(9) | *Francis et al.* (2002): |
| Holstein crossbred cattle (male and female)(10) | HG measurement alone is sufficient ($R^2$= 0.95) to predict LW in female calves from birth to six months of age(11) | *Ashwin et al.* (2019): |
| Crossed cows(12) | Effect of HG on live weight was $R^2$ = 0.53-0.78(13) | *Lukuju at al.* (2016) |
| Girolando cattle(14) | Step-by-step regression analysis: HG and the image of back surface affected live weight the most ($R^2$=0.70)(15) | *Weber et al.* (2020) |
| Limousin bulls(16) | LW was mainly determined by width of shoulders and withers height (R= 0.74)(17) | *Tőzsér et al.* (2020) |

11. *táblázat: Az élősúly testméretek alapján történő becslését bemutató néhány eredmény*
Fajta, ivar(1); eredmény(2); forrás(3); nőivarú szarvasmarhák, főleg zebu, illetve zebu x guzerat és zebu x Bos taurus keresztezések(4); Az élősúly legpontosabban az övméretből becsülhető, R=0,85)(5); holstein, svájci barna, keresztezett(6); Az élősúly legpontosabban az övméretből becsülhető, svájci barna: $R^2$=91,1%; keresztezettek: $R^2$=88,8%; holstein fríz: $R^2$=60,7%(7); őshonos, fríz, brahman, dán vörös és keresztezett(8); Az élősúly szoros összefüggésben (>0,90) volt a törzshosszal, övmérettel és marmagassággal. Az övmérettel való összefüggés kiemelkedően magas volt, r=0,96(9); holstein keresztezett, vegyes ivar(10); nőivarban születés és 6 hónapos kor között az övméretből megbízhatóan becsülhető az élősúly, $R^2$= 0,95(11); keresztezett tehenek(12); Övméret hatása az élősúlyra $R^2$ = 0,53-0,78 volt(13); giorlando szarvasmarha(14); lépésenkénti regresszió analízis: övméret és a hét felülete befolyásolta leginkább az élősúlyt($R^2$=0,70)(15); limousin bikák(16); az élősúlyt leginkább a vállszélesség és a marmagasság határozta meg(R= 0,74)(17)

## Conclusions

In prediction of the examined body measurements (withers' height, tail height, length of back, width of shoulders) different $R^2$% values were obtained (49.2; 92.5). Determination coefficients above 90% in cases of withers height and tail height imply that these parameters can be predicted by regression models accurately. Both traits are useful for planning corrective matings.

For length of back and width at shoulders, precise prediction was not possible by these parameters. More researches are needed to find out better fitting models.
Live weight could not be estimated accurately enough ($R^2$=68.5 – 68.6%) from the available body measurements (withers height, tail height, length of back, width at shoulders, width at hip bones). Since other results imply that chest girth is strongly correlated with live weight, it is considerable for Hungarian Limousine breeders to involve this trait into measured parameters.

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