Agronomy Research **21**(S2), 598–610, 2023
https://doi.org/10.15159/AR.23.030

Comparison of sire rams of the Latvian Dark-Head breed according to feed efficiency indicators as the beginning of genomic breeding research

I. Trapina[1,*], D. Kairisa[2] and N. Paramonova[1]

[1]University of Latvia, Institute of Biology, Laboratory of Genomics and Bioinformatics, Jelgava street 1, LV–1004 Riga, Latvia
[2]Latvian University of Life Sciences and Technologies, Faculty of Agriculture, Institute of Agrobiotechnology, Liela street 2, LV–3001 Jelgava, Latvia
[*]Correspondence: ilva.trapina@lu.lv

Received: January 30th, 2023; Accepted: April 27th, 2023; Published: April 29th, 2023

Abstract. In sheep (*Ovis aries*) farming, feed costs are the largest variable cost component. Breeders are showing an increased interest in breeding sire rams with improved feed efficiency characteristics because of the possibility that the offspring will have a higher value of this indicator. The result shows that for one ram, the progeny indicators tend to be variable. Currently, no marker has successfully explained enough of the variability of feed efficiency that they were used as part of a routine improvement program. The aim is to analyze feed efficiency indicators for lambs of sire rams of Latvian Dark-Head (LT; Latvijas tumšgalve) to identify sire rams producing lambs with potentially higher feed efficiency. Fattening data of 48 lambs from 13 sire rams were analyzed to determine the correlation of feed efficiency parameters. The average weight of lambs at birth was 4.08 ± 0.56 kg, while the average weight gain reached 47.43 ± 3.17 kg with an average fattening period of 73.27 ± 8.90 days. A strong and very strong correlation between the studied indicators of feed efficiency was revealed. The correlation between these indicators and live weight gain over for 60 days indicates their economic importance in meat production. Certain phenotypic and genotypic factors cause the influence on their value. The phenotypic influence may consist of environmental and external signs, but the genotypic influence is at the DNA level, which requires further study.

Key words: feed efficiency, lambs, Latvian Dark–Head, selection, sire rams.

INTRODUCTION

Raising lambs for selection purposes and meat production is the daily routine of modern sheep farmers. Every day, in a growing economy, it is necessary to be able to keep low production costs, of which about 70% are animal feeding costs (Berry & Crowley, 2013; Lima et al., 2017). To reduce feeding costs, cheaper feeds can be used, which often means a lower economic yield of meat products, for which feeding must be complete. However, the best method is to maintain an efficient herd with good breeding material. (Lima et al., 2013). Accordingly, reducing the fattening time of lambs in meat production is only possible with improved feed intake in the breeding process or the use of lambs with high feed efficiency (Hu et al., 2022).

Feed efficiency indicators can be loosely described as (1) ratio traits: Feed efficiency (FE), Feed conversion ratio (FCR), Relative growth rate (RGR), Kleiber's ratio (KR), or (2) regression or residual traits: Residual feed intake (RFI), Residual weight gain (RWG) and Residual intake and body weight gain (RIG). RGR and KR may be classified as comparative growth traits (Berry & Crowley, 2013)

As of 2018, there were 49.5 thousand (K) ewes and 73 sire rams in Latvia from a flock of 134.29K sheep. In 2018, Latvian Dark-Head (Latvijas tumšgalve; LT) sheep were bred for the implementation of the sheep breeding program in 35 farms, which had a total of 3,752 ewes, while 13 farms had 43 breeding rams (LAAA, 2022a). According to the EUROSTAT data (Eurostat, 2021), the number of sheep in Latvia in 2018 was 107.29K, but in December 2021 was 90.34K.

The Latvian Dark-Head sheep breed was created by crossing local Latvian sheep with Shropshire and Oxfordshire rams imported from Sweden and England. The first pedigree or breeder's book for LT rams was issued in 1939 (Vecvagars & Kairisa, 2018). Currently live weight of ewes of the Latvian Dark-Head breed is about 55–65 kg, rams - 95–120 kg, wool cut 3.5–4.5 and 5.0–6.0 kg, respectively. The average prolificacy of ewes is 150–160% (LAAA, 2022b).

Breeding of Latvian Dark-Head sheep in Latvia is carried out according to phenotypic and bloodline data, without information about values of feed efficiency indicators or carrying out genetic breeding. Therefore, this study aimed to analyze the Latvian Dark-Head breeds rams according to lambs' feed efficiency values. Previous studies have analyzed the fattening indicators (Bārzdiņa & Kairiša, 2015a), the novelty of this study lies in the analysis of the feed efficiency parameters. Scientifically studying sire rams by the indicators of feed efficiency of their offspring, is possible to give recommendations to breeders so that they can select for meat production those sire rams whose offspring have higher indicators. That way, not only breeders get offspring that grow faster and eat less, but the breed improves with each generation.

MATERIALS AND METHODS

Animals of intensive fattening

Based on the requirements of the breeding program of the Latvian dark–headed breed (LAAA, 2022a), every year the offspring of sire ram, certified for breeding activity, are selected. Forty–eight rams' lambs from 13 purebred sire rams of the Latvian Dark-Head breed (3 or 4 lambs per sire ram) were fattened at the ram breeding control station 'Klimpas' in collaboration with the association 'Latvian Sheep Breeders Association' in the summer months of 2022.

The age of the animals at the beginning of the process was 87.02 ± 7.14 days with an interval of 73 to 102 days (2.5–3.4 months), start body weight was 25.12 ± 2.50 kg.

According to the fattening control protocol, all offspring from the same sire ram were fattened in the same pen with a size of approximately 4 m^2 and equipped with a loose silo for combined concentrate and a slatted silo for hay. Straw is used as bedding. After each batch of lambs, the pen is cleaned and disinfected. There is natural ventilation through ceiling slots and windows equipped with anti–insect nets.

Lambs were fattened after an adaptation period of 1 to 2 weeks. During the study, lambs were fed unlimited combined concentrate (869.5 g kg^{-1} of consumed dry matter with 96.6 g kg^{-1} crude protein and 9.72 MJ kg^{-1} metabolizable energy) and hay (Šenfelde et al., 2020); in addition, mineral feed and licks were ensured. Water was provided from automatic waterers without limit.

Before the start of fattening and at the end of the process, the lambs were weighed on an electronic scale with an accuracy of 0.01 kg and measured using ultrasound (US) equipment Mindray Dp–50 Vet along the longest back muscle *(Longissimus dorsi)*, muscle depth and fat thickness of the 13^{th} rib.

The keeping of animals during the research met the animal welfare requirements.

Feed efficiency variables

Each indicator value for each sire ram was calculated as the average from offspring.

Delta of *Longissimus dorsi* muscle depth and fat thickness depth per 1 kg (ΔMD, and ΔFD per 1kg, accordingly) were calculated as the difference between the initial and final measurements of US per feeding time weight gain.

Based on the initial and final weight, the average daily weight gain (ADG) was calculated for each lamb and then the average for each ram from their offspring. Finally, the amount of dry matter intake (DMI) per day for lambs of one sire ram, kept in one pen, was calculated, taking into account that only 20% of hay was digested (Šenfelde et al., 2020). The result obtained per lamb is the average amount of dry matter consumed by 2–4 lambs during the fattening period.

Feed efficiency, Feed conversion ratio, Relative growth rate, Kleiber's ratio, and Residual indicators: Residual feed intake, Residual weight gain, Residual intake, and body weight gain as FE indicators were calculated by using formulas previously published (Berry & Crowley, 2013; Lima et al., 2017).

Statistical analyses

General and analytical statistics were performed with SPSS v.25 (IBM Corp., 2017), *Pearson* or *Spearman correlation* was calculated for lambs all together from measured and calculated values depending on normal distribution for data. In addition, the mean and standard error of the mean (*SEM*) were calculated for measurement data.

To calculate the difference between the parameters related to the FE in the experimental group of animals, the *ANOVA* test was used in the presence of a normal distribution and the *Kruskal–Wallis* test, in the absence of a normal distribution in at least one group. A significant result was determined if $P < 0.05$. The relationship between ram and lamb indicators was used to determine with association's coefficient *eta* (η), which ranges from 0, no relationship, to 1, excellent relationship.

RESULTS AND DISCUSSION

Description of rams according to offspring's fattening performance

The average body weight at birth of the offspring of 13 Latvian Dark-Head sire rams was 4.08 ± 0.08 kg with a difference from 2.80 to 5.40 kg. No statistically significant difference was found between the mean scores of average birth weight of the offspring of the rams (Fig. 1).

In early sources (Bārzdiņa & Kairiša, 2015b), it was found that the average weight of LT ram lambs born in summer was 3.70 ± 0.07 kg, which is about 300 g less than the stated values of the present study. Taking into account that the average weight of the offspring of the sire rams analyzed in our study was higher in almost all cases, except for LT_8, which had a similar weight, we can state an increase in the weight of lambs of Latvian breeds at birth over the past seven years.

According to the Latvian Breed Fattening Control Protocol, lambs from the same ram fed together are fattened to an average lamb weight in the range of 45 to 50 kg. In our study, LT lambs were fattened for an average of 73.27 ± 8.90 days with an interval of 60 to 94 days (at the end of fattening, lambs were around 5.21 months old). Considering that both the initial and final age of each lamb was different, the live weight correction was carried out on the 90th (beginning of fattening) and 150th (finishing of fattening) days (Fig. 1). The difference between the average weight of the offspring of LT sire rams on the 90th day of life is at the border of statistical significance (P = 0.056). However, on day 150th, the difference is statistically significant ($P = 7.10 \times 10^{-4}$). At both points of measurement, the relationship between the weight of the offspring and the ram is moderately close (η > 0.60). It can be assumed that the live weight of the offspring at particular moment (90th and 150th day) depends also on chosen sire ram.

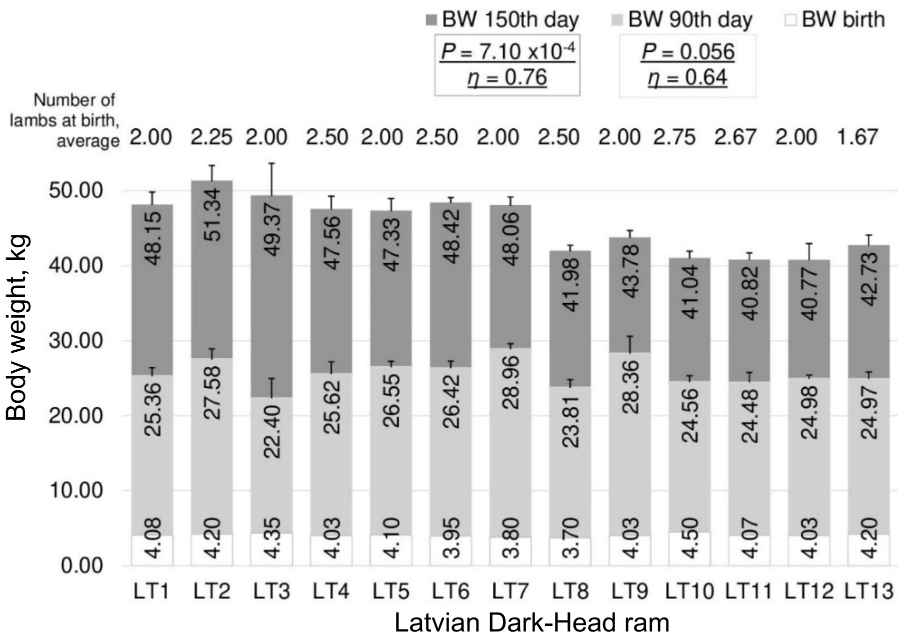

Figure 1. Mean of body weight (BW), kg, of lambs of Latvian Dark-Head rams at birth and corrected for day 90 and day 150. P – Statistical significance of mean with ANOVA; η – a measure of association.

Despite the same feeding conditions, there are rams whose offspring' average daily gain (ADG) prevails in relation to the rest of the lambs of the experimental cohort. On average, ADG in the experimental cohort of lambs was determined as 334.70 ± 9.96 g per day (Fig. 2) with a dry matter intake (DMI) of 1.65 ± 0.02 kg per day. According to the results obtained, a statistically significant difference was determined ($P = 7.66 \times 10–4$) in the mean value of ADG in the offspring of sire rams. In the LT breed, the presence of rams with an average ADG of the offspring was also found to differ by almost 200 grams. Interestingly, in the offspring of five rams from the experimental cohort, the prevalence of the ADG value in relation to the average total value was determined. This revealed difference in ADG values in the offspring of rams from the experimental herd is also confirmed by the value of the relationship index *Eta* ($\eta = 0.83$) or close relationship. Thus, among the 13 analyzed sires, there are those whose offspring have a high level of ADG, and there are rams with offspring that have a low value.

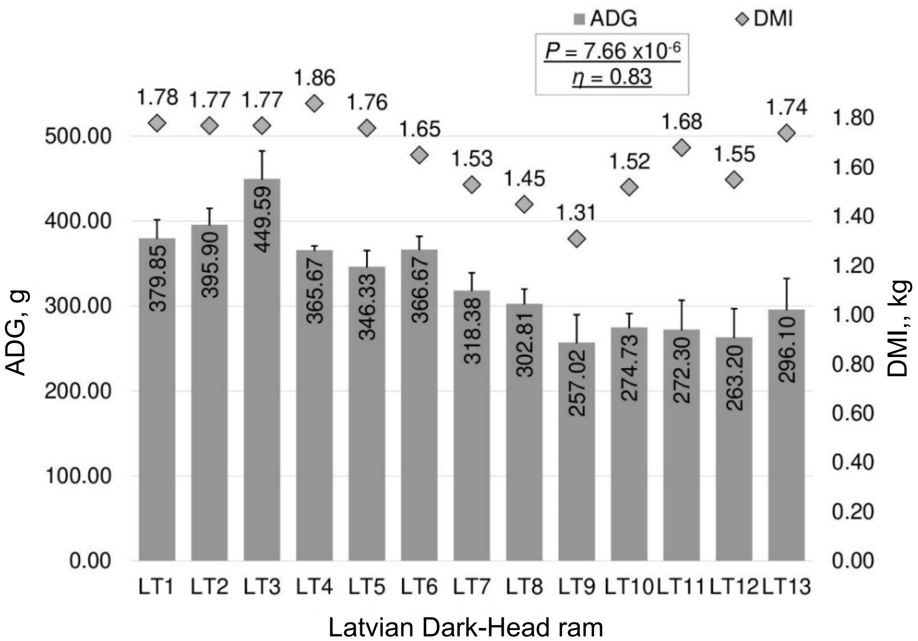

Figure 2. Mean of average daily gain (ADG), g, and dry matter intake (DMI), kg, per day in lambs from Latvian Dark-Head sire rams. *P* – Statistical significance of mean with *ANOVA*; η – a measure of association.

ADG values determined in the present and previous (Kairiša & Bārzdiņa, 2016) studies were found to be similar. However, in the experimental lambs' cohort of 2016, aged 81–99 days, the highest ADG value was found, which, however, turned out to be lower than the average value of this indicator from the present cohort for our three top rams (LT_1 – LT_3; Fig. 2).

According to the results of the study, LT lambs gained 20.08 ± 0.60 kg in weight over 60 days (ΔBW 60d) with an interval from 11.84 to 31.90 kg (Table 1). Thus, the difference between the lightest and the heaviest lamb was on average 20 kg. A statistically significant difference in ΔBW values, as well as a close relationship between the rams of the experimental cohort, was determined at the fattening period of 60 days. These data confirm our assumption that the offspring of rams from the experimental herd have potentially different values of feed efficiency, which have both phenotypic and genotypic effects.

The data obtained by measuring the depth of the *Longissimus dorsi* muscle (ΔMD) and adipose tissue at the level of the 13th rib using US were calculated per 1 kg of weight gain (Table 1). It was found that this average value of the growth of the long back muscle per 1 kg statistically significantly differs in the offspring of LT sire rams ($P = 1.26{\times}10^{-2}$), however, in relation to the growth in adipose tissue depth per 1 kg, no statistical difference was found. For the LT breed, ΔMD per kg is 0.46 ± 0.02 mm, with a final average MD value of 31.01 ± 0.21 mm. Among 13 sire rams, only six showed a prevailing value for offspring indicator in relation to the average value for the breed. Thus, it can be assumed that these sire rams can improve the breed in this indicator.

Table 1. Mean of average of fattening traits in lambs from Latvian Dark-Head sire rams

Rams Nr	Traits, mean ± SEM ΔBW in 60 days, kg	ΔFD, mm per 1 kg	ΔMD, mm per 1kg
All*	20.08 ± 0.60 (11.84–31.90)	0.044 ± 0.003 (0.006–0.084)	0.46 ± 0.02 (0.25–0.80)
LT_1	**22.79 ± 1.30**	0.030 ± 0.007	0.35 ± 0.02
LT_2	**23.76 ± 1.14**	0.036 ± 0.013	0.43 ± 0.06
LT_3	**26.98 ± 1.97**	0.041 ± 0.004	**0.54 ± 0.09**
LT_4	21.94 ± 0.30	0.033 ± 0.009	0.37 ± 0.04
LT_5	20.78 ± 1.14	0.036 ± 0.009	0.38 ± 0.03
LT_6	22.00 ± 0.92	0.047 ± 0.008	0.47 ± 0.02
LT_7	19.10 ± 1.24	0.036 ± 0.016	0.47 ± 0.04
LT_8	18.17 ± 1.03	0.050 ± 0.007	0.36 ± 0.03
LT_9	15.42 ± 1.97	**0.062 ± 0.011**	0.46 ± 0.02
LT_10	16.48 ± 0.98	**0.062 ± 0.009**	**0.61 ± 0.05**
LT_11	16.34 ± 2.07	0.048 ± 0.003	**0.54 ± 0.07**
LT_12	15.79 ± 2.03	**0.067 ± 0.011**	**0.67 ± 0.07**
LT_13	17.77 ± 2.18	0.039 ± 0.004	0.46 ± 0.11
P	$8.53{\times}10^{-6}$	0.15	$1.26{\times}10^{-2}$
η	0.83	0.59	0.73

ΔMD – delta of *Longissimus dorsi* muscle depth per 1kg; ΔFD – delta of Fat thickness depth per 1kg; ΔBW 60 – change in body weight in 60–day period. All – all lambs with min and max values in brackets; *P* – the statistical significance of mean with ANOVA or Kruskal-Wallis (underlined) test; η – a measure of association; in bold the first three values and underline the last three.

However, in our study, none of the sire rams was found with the prevailing average values of all previous indicators in relation to the rest of the rams. Thus, it is assumed that no animal from our experimental herd can provide the best quality indicators in the future, in relation to its offspring. For example, ram LT_10 is in the top three in terms of birth weight, as well as ΔMD and ΔFD, but has one of the lowest values of the average daily gain. Animal LT_3 has very good indicators regarding birth weight, ΔFD, and best ADG, but has a higher average DMI than the average for all rams.

Description of sire rams according to feed efficiency indicators

Feeding efficiency indicators were calculated from fattening performance: ratio traits: FE, FCR (Fig. 3) and RGR, KR (Fig. 4), and residual traits: RWG, RFI, and RIG (Table 2). A statistically significant difference was established between all indicators of the feeding efficiency trait in LT rams of the experimental herd. This effect may be due to differences in phenotypic characteristics, as well as in the genetic background associated with this tract, between animals of the same breed (Lima et al., 2017). We also assume the possibility of genetic and phenotypic correlations between the constituent feeding efficiency traits, the analysis of which is also presented in this study.

Feed efficiency and Feed conversion ratio

The first two traits are Feed efficiency (FE) and Feed conversion ratio (FCR), which are inverse to each other, or FCR = 1/FE (Lima et al., 2017). The values of the FCR (kg of feed dry matter intake per kg of live weight gain) for lambs vary from 4 to 5 (for FE grams from 200 to 250) on highly concentrated ratio, from 5 to 6 (FE, g, 166.67–200) falls on some good quality feeds and more than 6 (> 166.67 g) - on feeds on lower quality food (National Research Council, 2007).

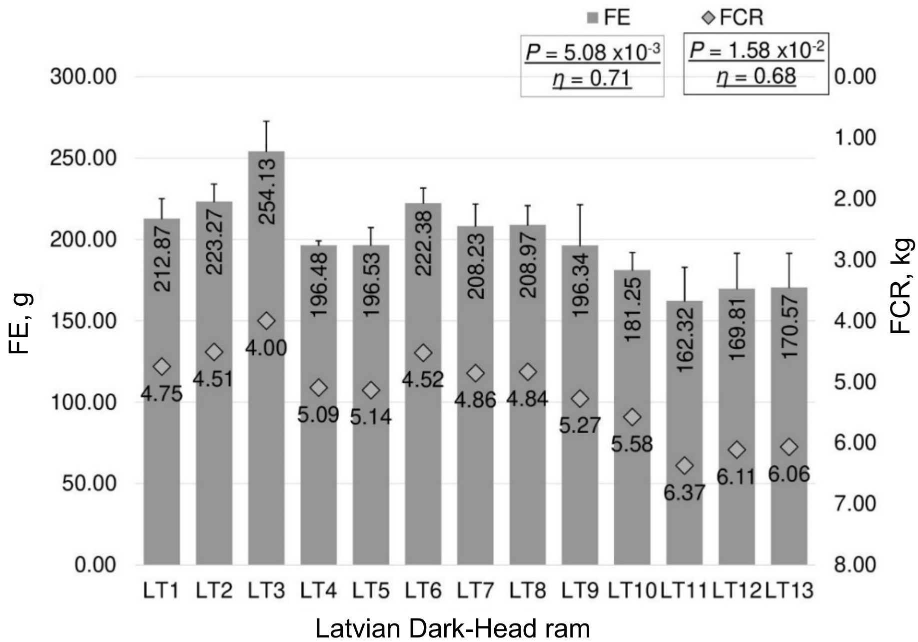

Figure 3. Mean of Feed efficiency (FE), g, and Feed conversion ratio (FCR), kg, per day for lambs of Latvian Dark-Head rams. P – Statistical significance of mean with *ANOVA*; η – a measure of association.

In the LT breed, the average FCR is 5.09 ± 0.15 kg with an interval from 3.33 to 7.92. That means that 1 kg of weight gain requires an average of 5.09 kg of dry matter. However, when comparing rams (Fig. 3), six has an average FCR of less than 5.00, and the rest rams range from 5 to 6. Thus, out of 13 sires, half produce lambs with a high FCR value. There must be some other factors, molecular or genetic, that may positively influence high FCR and improve breeding.

Relative growth rate and Kleiber's ratio

In this study, the Relative growth rate (RGR), which is also an indicator of feeding efficiency (Berry & Crowley. 2013), as well as the Kleiber ratio (KR), an indicator of growth efficiency regardless of body size (Köster et al., 1994), were also calculated. For LT lambs, the average RGR value was 0.43 ± 0.01. According to our data (Fig. 4), the sire ram (LT_3) with the lowest FCR value also has the highest average RGR score, indicating the high potential of this ram as a producer of lambs with a potentially high feeding efficiency value.

Based on the published data, rams have a higher average RGR than ewes (Kesbi & Tari, 2015). The highest value of this indicator is observed during the period when the ewe nursing the lamb, but after the end of nursing, it decreases. In our study, RGR values for the time periods in the period from weaning to 6–9 months were found to be similar or higher relative to other breeds (Kesbi & Tari, 2015; Lima et al., 2017; Ghafouri–Kesbi & Eskandarinasab, 2018; Ehsaninia, 2022). These data confirm the competitiveness of the LT breed. However, for its subsequent improvement, it seems necessary to use sire rams with the highest indicators related to the feeding efficiency tract.

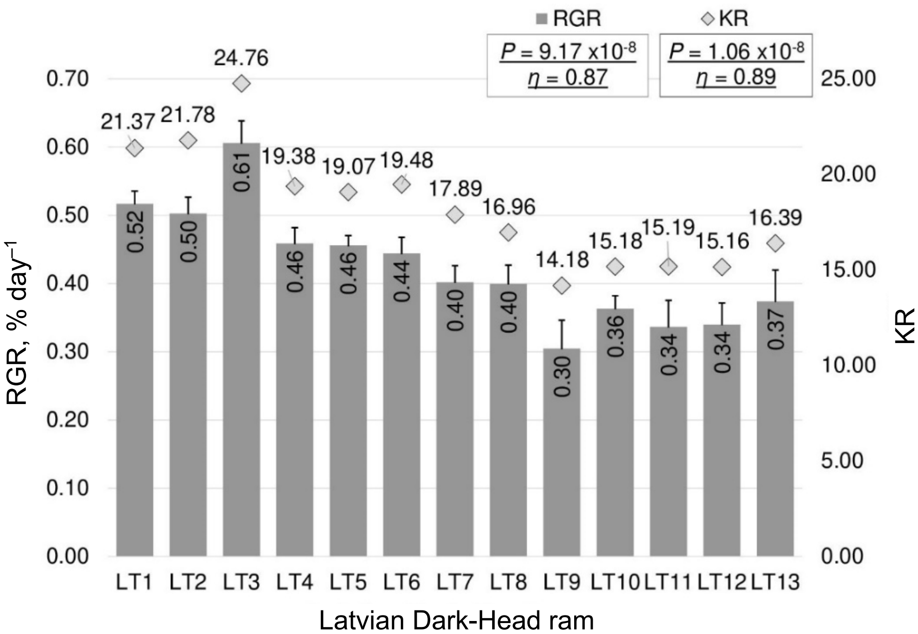

Figure 4. Mean of relative growth rate (RGR) and Kleiber's ratio (KR) for lambs of Latvian Dark-Head rams. *P* – Statistical significance of mean with *ANOVA*; *η* – a measure of association.

Based on our calculations, for six sire rams the KR average value from the experimental cohort turned out to be higher than the average for the breed (18.46 ± 0.49) which suggests that the potential for these animals as producers of offspring with improved feeding efficiency indicator (Fig. 4). The values of the KR obtained by us turned out to be significantly higher than in other breeds of sheep in the corresponding age (Talebi, 2012a; Kumar et al., 2017; Venkataramanan et al., 2019; Bansal et al., 2021; Ehsaninia, 2022) However, it should be taken into account that at the moment there is no clearly established norm for this feeding efficiency related parameter in lambs.

The high correlation between KR and FE indicators shows that animals with higher KR require less energy to maintain weight and growth (Bansal et al., 2021). In addition, the highest values of the Kleiber coefficient indicate an increase in body weight gain at the same metabolic weight ($BW^{0.75}$), which means that higher growth is achieved without an increase in the cost of energy for maintenance (Talebi, 2012b).

Residual feed intake and Residual weight gain

The expected DMI and ADG values were calculated using the $BW^{0.75}$ parameter for all LT lambs from the experimental cohort. Based on the obtained data, the Residual feed intake (RFI) and Residual weight gain (RWG) parameters (Table 2) and both standardized values for RIG were further calculated (Lima et al., 2017). As a result, all three residual values were, on average, equal to 0.

RFI measures the economic value of feed consumption (Berry & Crowley, 2013). The RFI values in the experimental cohort of lambs from LT breeds were determined in the range from –0.27 to 0.25 kg (Table 2). These values indicate the presence of animals consuming dry matter both 0.27 kg less than planned and 0.25 kg more than they are supposed to according to metabolic weight. According to the results of this study, a negative value of the RFI parameter was revealed for half of the sire rams. Thus, their offspring would be expected to consume less dry matter and have a lower DMI than would be expected from calculations based on ADG and metabolic body weight at the end of the fattening period. It was found a statistically significant difference between the average RFI for sire rams ($P = 1.27 \times 10^{-13}$), and the relationship between sire rams and offspring data is closely related ($\eta = 0.95$). Thus, it is assumed that among the 13 rams analyzed, there are those whose offspring need less dry matter to reach marketable weight.

Table 2. Feed efficiency residual traits of Latvian Dark-Head rams

Rams Nr	Feed efficiency residual traits. mean ± *SEM*		
	RFI, kg day^{-1}	RWG, g day^{-1}	RIG
All*	0.00 ± 0.02 (–0.27–0.25)	0.00 ± 6.56 (–96.83–203.62)	0.00 ± 0.26 (–4.17–3.38)
LT_1	0.05 ± 0.02	**28.48 ± 5.63**	0.25 ± 0.24
LT_2	0.03 ± 0.02	**30.90 ± 12.89**	0.46 ± 0.44
LT_3	–0.06 ± 0.03	**86.71 ± 15.26**	**2.41 ± 0.57**
LT_4	<u>0.19 ± 0.02</u>	<u>–46.99 ± 17.94</u>	<u>–2.64 ± 0.56</u>
LT_5	0.09 ± 0.01	–15.13 ± 4.66	–1.11 ± 0.18
LT_6	–0.02 ± 0.02	4.31 ± 13.16	0.27 ± 0.47
LT_7	**–0.11 ± 0.02**	21.85 ± 11.34	1.36 ± 0.43
LT_8	**–0.16 ± 0.02**	21.45 ± 12.75	**1.78 ± 0.46**
LT_9	**–0.22 ± 0.04**	–1.27 ± 22.55	**1.77 ± 0.83**
LT_10	–0.04 ± 0.01	–30.81 ± 8.01	–0.39 ± 0.28
LT_11	<u>0.12 ± 0.03</u>	<u>–59.95 ± 13.12</u>	<u>–2.30 ± 0.55</u>
LT_12	–0.02 ± 0.02	–18.13 ± 4.25	–0.23 ± 0.25
LT_13	<u>0.15 ± 0.04</u>	<u>–55.00 ± 18.09</u>	<u>–2.43 ± 0.71</u>
P	1.27×10^{-13}	3.94×10^{-8}	3.03×10^{-9}
η	0.95	0.88	0.90

RFI – Residual feed intake; RWG – Residual weight gain; RIG – Residual intake and body weight gain; All – all lambs with min and max value in brackets; *P* – the statistical significance of mean with ANOVA test; the first three values are in bold and the last three are underlined.

According to published data (Tortereau et al., 2020), when selecting rams of the Romane breed according to the increased RFI, already in the first generation of their offspring, a decrease in the DMI required for feeding was observed and, thus, the cost of fattening was reduced.

A similar result is observed in the case of our study: a high statistically significant difference ($P = 3.94 \times 10^{-8}$) between rams in the experimental cohort, as well as a close correlation ($\eta = 0.88$), is observed between the sire rams and lambs' cohorts when calculating the RWG parameter (Table 2). For example, the calculated ADG for LT_3 ram was found to differ from expected by an average of 86.71 ± 15.26 g per day; in the case of LT_11, the difference was –59.95 ± 13.12 g per day, or weight gain was less than expected based on metabolic weight calculations and the DMI used.

Residual intake and weight gain

Using the Residual Intake and Growth (RIG) indicators, it is possible to identify fast–growing animals, with the highest ADG and the lowest DMI, consuming less feed than the population average, with no difference in BW. Thus, an increase in the value of the RGI parameter, in turn, leads to an improved ratio of ADG and DMI indicators (Lima et al., 2017). With a higher RIG value, the feeding efficiency increases correspondingly, which characterizes animals with higher growth rates and lower fat content, without affecting the quality of meat and carcass. In addition, if this characteristic is present in an animal, the time it is kept until it reaches its marketable weight is reduced (Arce–Recinos et al., 2021).

According to our data (Table 2), among certain sire rams from the experimental cohort, an average RIG significantly prevailed in relation to the other (P = 3.03 x10^{-9}; η = 0.90) and reflected improved characteristics of these animals.

In the present study, in our experimental cohort, one sire ram (LT_3) was identified with prevailing values of all the above indicators (excluding the RIF index) associated with feed efficiency (Figs 3, 4 and Table 2). Thus, it is assumed that this animal has an increased potential for improving the breed.

However, in the context of the obtained results, it seems necessary to find out the features and differences at the level of the genetic background related to the feeding efficiency tract in sheep with high and low rates of the above indicators in order to determine genetic markers to improve selection in the LT breed for this trait.

Correlation of feed efficiency indicators

Strong and negative correlation (Fig. 5) in all analyzed LT lambs were identified between FCR and RGR (–0.74) and FCR and KR (–0.76), but strong and positive correlation – between FE and RGR (0.82) and KR (0.85). Very strong and positive correlations were identified between RGR and KR (0.99) traits in LT lambs. Considering that similar algorithms are used in the calculation of feed efficiency ratio indicators; the correlation between feed efficiency ratio traits and residual traits is more significant.

The residual traits: RFI, RWG and RIG, has a statistically significant correlations with all other feed efficiency indicators for LT lambs, except RIF hasn't correlation with RGR and KR.

In case of RFI indicator have weak correlations with FE/FCR (–0.43/0.40), which indicates the possibility that using RFI and FE/FCR in breeding is possible to promote weight gain in LT lambs with lower feed intake than expected.

There is also moderately strong, negative correlation between RFI and RWG (–0.60), which shows, that there already are lambs with more than expect ADG and less than expected DMI. These lambs and their sire rams are necessity to improve meat production characteristics of the LT breed.

Correlations, but phenotypic and genetic, between RGR or KR and RIG has also been found in other sheep populations (Knott et al., 2003; Talebi, 2012b). In LT lambs also are correlation between this indicators: 0.42 in both cases. So LT lambs with a high RGR and/or KR will also have a high RIG. But RIG indicators have stronger correlation with FE/FCR (0.68/–0.67) in LT lambs.

The found correlation between feed efficiency indicators, except RFI, and live weight gain over a period of 60 days indicates their economic importance in meat production. Correlation ΔBW 60d with FE/FCR are 0.89/–0.81, but with RGR and

KR – 0.95 and 0.97, respectively, which means that improving feed efficiency improves weight gain in intensive fattening over a 60–day period.

-1.0 0 1.0

Traits	FE	FCR	RGR	KR	RFI	RWG	RIG	BW 90d	BW 150d	ΔBW 60	$BW^{0.75}$	ADG	DMI	ΔMD	ΔFD	MD final
FCR	**-0.96**															
RGR	**0.82**	**-0.74**														
KR	**0.85**	**-0.76**	**0.99**													
RFI	**-0.43**	**0.40**	0.00	0.00												
RWG	**0.79**	**-0.75**	**0.75**	**0.74**	**-0.60**											
RIG	**0.68**	**-0.67**	**0.42**	**0.42**	**-0.89**	**0.89**										
BW 90d	-0.09	0.06	**-0.32**	-0.22	0.01	-0.26	-0.15									
BW 150d	**0.73**	**-0.65**	**0.64**	**0.72**	0.00	**0.42**	0.23	**0.49**								
ΔBW 60	**0.89**	**-0.81**	**0.95**	**0.97**	0.00	**0.66**	**0.37**	-0.12	**0.80**							
$BW^{0.75}$	**0.61**	**-0.60**	**0.32**	**0.37**	0.00	0.00	0.00	0.24	0.65	0.57						
ADG	**0.89**	**-0.81**	**0.95**	**0.97**	0.00	**0.66**	**0.37**	-0.12	**0.80**	**1.00**	**0.57**					
DMI	0.17	-0.17	**0.68**	**0.69**	**0.72**	0.08	**-0.34**	-0.06	**0.49**	**0.67**	0.16	**0.67**				
ΔMD	**-0.34**	0.26	-0.28	**-0.30**	-0.06	-0.09	-0.02	-0.20	**-0.44**	**-0.37**	**-0.42**	**-0.37**	-0.27			
ΔFD	**-0.33**	0.28	**-0.46**	**-0.47**	-0.20	-0.21	0.00	0.00	**-0.40**	**-0.46**	-0.21	**-0.46**	**-0.46**	**0.51**		
MD final	0.06	-0.11	0.02	0.04	0.19	-0.17	-0.20	0.10	0.17	0.12	**0.31**	0.12	**0.55**	**0.43**	0.28	
FD final	-0.07	0.11	**-0.29**	**-0.32**	-0.27	-0.15	0.06	-0.10	-0.27	-0.24	0.14	-0.24	**-0.52**	**0.32**	**0.80**	**0.38**

Figure 5. Correlation of feed efficiency indicators for lambs. FCR – Feed conversion ratio; FE – Feed efficiency; RGR – Relative growth rate; KR – Kleiber's ratio; RFI – Residual feed intake. RWG – Residual weight gain; RIG – Residual intake and body weight gain; BW – body weight at 90th day (90d), 150th day (150d); ΔBW 60 – change in body weight in 60 day period; $BW^{0.75}$ – metabolic weight; ADG – average day gained weight; DMI – dry matter intake; ΔMD – Delta of *Longissimus dorsi* muscle depth per 1kg; ΔFD – fat thickness depth per 1 kg; MD final – *Longissimus dorsi* muscle depth at the end of fattening. FD final – fat thickness depth at the end of fattening Value with statistical significance $p < 0.05$ is highlighted in bold.

As a result of our studies, a correlation was established between DMI and RGR, KR, BW at day 150 and body weight gained at 60 days, which indicates an unknown factor, for example differences in DNA level, affecting feed intake of lambs, since feed was available all lambs without restrictions.

CONCLUSIONS

The feeding productivity of LT sheep was determined to be medium in our study. Obviously, this parameter should be improved, considering, however, the preservation of breed specificity. This problem can be solved by selecting animals for breeding with a clear phenotypic description, related to the current breed, and a deterministic genotype associated with high rates of feed efficiency indicators. Based on the results of the analysis of the above feed efficiency indicators, several sire rams from our experimental cohort can be selected for subsequent selection improvement.

Thus, additional studies are needed to clarify the quality of feed efficiency indicators when using other ewe genetic materials. It is desirable, however, to conduct an additional experimental trial for fattening a cohort of offspring from other ewes and rams with improved parameters, selected in the current study.

The results of our study indicate that the LT breed has sire rams whose offspring have a higher feed efficiency compared to the offspring of other sire rams. According to the most prevailing indicators of feed efficiency among the animals of the experimental herd, it is possible to provide recommendations to breeders for the best breeding selection using the identified sire rams, whose offspring have higher indicators. Such selection within a certain breed will improve the overall economic performance of the herd: breeders not only get offspring that grow faster and eat less, but also the effect of a systematic improvement of the breed with each generation is obtained.

Feed efficiency indicators have common effects in LT breed sire rams. Possibly, the phenotypic effects determine the living conditions or environment and external signs of the ram, but the genetic effect is at the DNA level, which requires further study. This possibility needs to be tested in future studies.

ACKNOWLEDGEMENTS. The study was funded by LZP–2021/1–0489 project: 'Development of an innovative approach to identify biological determinants involved in the between–animal variation in feed efficiency in sheep farming.'

REFERENCES

Arce-Recinos, C., Chay-Canul, A.J., Alarcón-Zúñiga, B., Ramos-Juárez, J.A., Vargas-Villamil, L.M., Aranda-Ibáñez, E.M., del Carmen Sánchez-Villegas, N. & da Costa, R.L.D. 2021. Feed efficiency indexes in hair sheep: Meat quality and associated genes. Review. *Revista Mexicana De Ciencias Pecuarias* **12**(2), 523–552. https://doi.org/10.22319/RMCP.V12I2.5642

Bansal, G.K., Kumar, V., Nagda, R. & Hada, R. 2021. Genetic investigation on Kleiber ratio in Sonadi sheep. Journal of Entomology and Zoology Studies, **9** (2), 1038–1041.

Bārzdiņa, D. & Kairisa, D. 2015a. Latvia Dark Head bred lambs growth parameter analysis. *Proceedings of the scientific and practical conference 'Harmonious Agriculture*' 172–178.

Bārzdiņa, D. & Kairiša, D. 2015b. The production and quality analysis of Latvian darkhead breed lambs. Nordic View to Sustainable Rural Revelopment. *Proceedings of the 25th NIF congress*, 361–366.

Berry, D.P. & Crowley, J.J. 2013. CELL BIOLOGY SYMPOSIUM: Genetics of feed efficiency in dairy and beef cattle1. *Journal of Animal Science* **91**(4), 1594–1613. https://doi.org/10.2527/jas.2012–5862

Ehsaninia, J. (2022). Growth rate and efficiency–related traits in Kermani lambs: Estimations of (co)variance components and genetic parameters [Preprint]. In Review. https://doi.org/10.21203/rs.3.rs–1961845/v1

Eurostat, 2021. https://ec.europa.eu/eurostat/databrowser/view/tag00017/default/table?lang=en Accessed 29.11.2022.

Ghafouri–Kesbi, F. & Eskandarinasab, M. 2018. Heritability of relative growth rate and its relationship with growth–related traits in Afshari sheep. *Gene Reports* **12**, 225–229. https://doi.org/10.1016/j.genrep.2018.07.006

Hu, G., Do, D.N., Davoudi, P. & Miar, Y. 2022. Emerging Roles of Non–Coding RNAs in the Feed Efficiency of Livestock Species. *Genes* **13**(2). https://doi.org/10.3390/genes13020297

IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.
Kairiša, D. & Bārzdiņa, D. 2016. Different age analysis of fattening results Latvian blackhead breed lamb. *Proceedings of the scientific and practical conference "Harmonious Agriculture"* 168–173. (in Latvian)
Kesbi, F.G. & Tari, A.R. 2015. Relative growth rate in sheep: Heritability and relationship with absolute growth rate and body weight. *Songklanakarin J. Sci. Technol*. **37**(1), 21–27.
Knott, S., Leury, B., Cummins, L., Brien, F. & Dunshea, F. 2003. Relationship between body composition, net feed intake and gross feed conversion efficiency in composite sire line sheep. *Progress in Research on Energy and Protein Metabolism* **109**, 525–528.
Köster, E., van der Westhuizen, J. & Erasmus, G. J. 1994. Heritability estimates for different Kleiber ratios obtained from growth performance data in a Hereford herd. *South African Journal of Animal Science* **24**(2), 71–72.
Kumar, D.A.P., Prakash, M.G., Gupta, B.R., Raghunandan, T. & Chandra, A.S. 2017. Average daily gain and Kleiber Ratio in Deccani Sheep. *The Pharma Innovation Journal*, **6** (6), 194–197.
LAAA. 2022a. Latvia Dark-Head sheep breeds. Selection program. Available at https://www.laaa.lv/data/uploads/ciltsdarba–programmas/2022/LT_audz_progr_prec__24_03_2022.docx (in Latvian)
LAAA. 2022b. Latvian Dark-Head breed. Available at https://www.laaa.lv/data/uploads/skirnu_apraksti/Latvijas_tumsgalve.pdf
Lima, N.L.L., Ribeiro, C.R. de F., de Sá, H.C.M., Leopoldino Júnior, I., Cavalcanti, L.F.L., Santana, R.A.V., Furusho–Garcia, I.F. & Pereira, I.G. 2017. Economic analysis, performance, and feed efficiency in feedlot lambs. *Revista Brasileira de Zootecnia* **46**(10), 821–829. https://doi.org/10.1590/S1806–92902017001000005
Lima, N.L.L., Silva Sobrinho, A.G. da, Almeida, F.A. de, Endo, V., Zeola, N.M.B.L., Almeida, A.K. de & Sampaio, A.A.M. 2013. Quantitative and qualitative characteristics of the non–carcass components and the meat of lambs fed sunflower seeds and vitamin E. *Revista Brasileira de Zootecnia* **42**, 51–60. https://doi.org/10.1590/S1516–35982013000100008
National Research Council. 2007. *Nutrient requirements of small ruminants*. National Academies Press. 362 pp.
Šenfelde, L., Kairiša, D. & Bārzdiņa, D. 2020. Effect of concentrate feeding technology on nutrient digestibility in Latvian Dark-Head lambs. *Agronomy Research* **18**(S1), 1000–1009. https://doi.org/10.15159/AR.20.143
Talebi, E. 2012a. Heritability estimates for some growth traits and Kleiber ratios in Karakul sheep. The *Indian Journal of Animal Sciences* **82**, 620–623.
Talebi, M.A. 2012b. Feed intake, feed efficiency, growth and their relationship with Kleiber ratio in Lori–Bakhtiari lambs. *Archiva Zootechnica* **15**(4), 33–39.
Tortereau, F., Marie–Etancelin, C., Weisbecker, J.L., Marcon, D., Bouvier, F., Moreno–Romieux, C. & François, D. 2020. Genetic parameters for feed efficiency in Romane rams and responses to single–generation selection. *Animal* **14**(4), 681–687. https://doi.org/10.1017/S1751731119002544
Vecvagars, J. & Kairiša, D. 2018. Sheep population structure of Latvia darkhead breed. *Proceedings of the scientific and practical conference 'Harmonious Agriculture'*, pp. 64–68 (in Latvian).
Venkataramanan, R., Subramanian, A., Sivaselvam, S. N., Sivakumar, T. & Sreekumar, C. 2019. Genetic parameters for Kleiber ratio and its relation to other body weight traits in Nilagiri and Sandyno sheep. *Indian Journal of Animal Science* **86**(5), 559–563.