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Feed efficiency indicators and hormones related to nutrient metabolism in intensive fattened lambs of sire rams of different sheep breeds in Latvia

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Abstract. The feed efficiency increase of each sheep indicates its profitability. Production costs and the environmental impact of animal husbandry are reduced as feed efficiency improves. The gastrointestinal tract is a source of hormones and is important in regulating feed intake and nutrient utilization. The study analyses the relationship between feed efficiency indicators and hormone levels in Latvian sheep breeds. After control fattening, blood samples were taken from 76 lambs, representatives of six Latvian breeds, for seven hormonal analyzes and seven feed efficiency indicators. Feed efficiency, Feed conversion ratio (FCR), Relative growth rate, Kleiber ratio (KR), Residual feed intake (RFI), Residual weight gain, and Residual intake were calculated from daily weight gain and amount of dry matter. Interbreed differences and relationships between indicators/hormones were identified. The best scores of feed efficiency were found for the lamb rams of the Dorper breed; the Latvian black-head was the second according to these indicators. The mean FRC for lambs was determined to be 5.13 ± 0.13 kg with a range of 2.98–10.15 kg; the mean KR was 18.11 ± 0.39 with a range of 8.78–26.88; the mean RFI was in the range of -0.51 to 0.42 kg. A statistically significant difference was found between the breeds for all feed efficiency indicators. Biochemical parameters (IGF-1, insulin, and glucose) were found to be in correlation with feed efficiency indicators. Our results show that Latvian sheep breeds differ in fattening performance. To improve breeds without crossing them, subsequent genetic analysis of breed differences is necessary.

Key words: breeding, fattening, feed efficiency, hormones, Latvian sheep.

INTRODUCTION

In sheep breeding, 60–70% of the daily costs are for their fattening (Lima et al., 2017). Therefore, to reduce these costs, raising animals with a higher value or feed efficiency is necessary, which will contribute to the profitability of this production (Berry & Crowley, 2013; Lima et al., 2017).

Improved feed efficiencies indicators such as Feed efficiency (FE), Feed conversion ratio (FCR), Relative growth rate (RGR), Kleiber ratio (KR), Residual feed intake (RFI), Residual weight gain (RWG), and Residual intake and body weight gain (RIG), reduced the ratio of average weight gain and amount of feed required what in final reduce production costs (Berry & Crowley, 2013). In addition, this process also reduces the environmental impact of animal husbandry (Hu et al., 2022).

Many factors affect feed efficiency, including body composition, digestion, and metabolism of nutrients (Zhang et al., 2017). In addition, the endocrine system could affect feed efficiency by regulating feed intake and nutrient utilization (Richardson et al., 2004). The gastrointestinal tract with attached glands is the source of secretes hormones, which are important in regulating feed intake (insulin) and nutrient use (glucose, insulin, and IGF-1). Previous studies have reported that the systemic insulin concentration in low-feed efficiency steers is greater than in high-feed efficiency steers (Richardson et al., 2004). In addition, plasma concentrations of thyroxine T4 and adrenocorticotropic hormone (ACTH) were lower in high-feed efficiency than in low-feed efficiency cows (Walker et al., 2015).

The world's sheep stock rose to a new record high of 1.266 billion head in 2021 (IWTO, 2022), including approximately 1,400 breeds (Kawęcka, 2022), classified according to (1) type production - wool, meat, milk, fur and other; (2) phenotypic characteristics such as head colour (white head, dark head), tail length and ability to accumulate fat (short, long, fat), presence of horns (horned or dehorned); (3) by breeding place - Germany, Latvia, Estonia, Spain and other or by topographical habitat - lowlands, highlands (LAAA, 2023). The number of sheep in Latvia in 2018 was 107.29 thousand, having increased in December 2021 to 90.34 thousand, according to Eurostat data (Eurostat, 2021). There are currently ten sheep breeding programs in Latvia (LAAA, 2022), according to which Latvian breeds are divided into maternal and paternal breeds according to their characteristics.

Maternal breeds such as Latvian dark-head (Latvijas tumšgalve; LT) and Merinolandschaf (MLS), also known as Württemberger, have good fertility and the ability to rear lambs, while paternal breeds: Île de France (IF), Charollais (CH), Dorper (DOR) and Texel (TEX), have fattening abilities - quick monitoring, feed conversion, and carcass quality (LAAA, 2023).

The analyzed parameters of feed efficiency and hormone levels related to nutrient metabolism in single-litter lambs of different breeds are variable and affects meat quality (Zhang et al., 2017). Until now, there is no information on whether feed efficiency indicators and hormone levels, which also depend on the feed used, differ in different breeds of Latvian sheep reared under the same conditions.

The study aims to analyze the value of feed efficiency indicators and the level of hormones related to nutrient metabolism in Latvian sheep breeds. Scientifically based knowledge of breed differences and the relationship of feed efficiency indicators with specific hormones can be used as an economical and rapid breeding tool in the selection of animals within the same herd with the highest feed efficiency indicators. In this way, breeders will be able to systematically improve the breed of sheep with each generation.

MATERIALS AND METHODS

Animals of intensive fattening

Based on the requirements of the breeding program of the breeds (LAAA, 2022), every year, the offspring of the sire ram, certified for breeding activity, are selected and analyzed to estimate the sire rams. Seventy-six (76) lambs (63.16% LT) from 22 sire rams of six breeds: Latvian dark-head (48 lambs), Merinolandschaf (8 lambs), Île de France (6 lambs), Charollais (3 lambs), Dorper (5 lambs) and Texel (6 lambs), were included in controlled fattening from March to October 2022. All lambs were born as twins, triplets or quadruplets from different ewes and health status was assessed prior to inclusion in the study so that there were at least two lambs per sire ram from the breed. This study was carried out in cooperation with Latvian Sheep Breeders' Association at the ram breeding control station (Table 2). Lambs were fattened for 66.38 ± 1.27 days with an interval of 44 to 83 days.

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

Lambs were fattened with unlimited water from automatic drinkers, a 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; in addition, mineral feed and licks were ensured. The dry matter and chemical composition of grass hay has been published previously by Šenfelde and colleagues (2020).

The live weight of lambs was determined before and after intensive fattening by weighing with calibrated and certified electronic scales (accuracy ± 0.01). As a result, the average initial body weight of the lambs was 25.12 ± 2.50 kg (approximate age 2.5–3.4 months) according to the controlled fattening process established in Latvia for each breed. The end of fattening was determined by the average final body weight of at least 45–50 kg for all offspring from one sire ram, fattened in one pen, according to the control fattening protocol.

Feed efficiency variables

The average daily gain (ADG) in grams for each lamb was calculated based on the initial and final weights, which were then used to calculate the breed average. The amount of dry matter consumed per day (DMI) in kilograms is calculated as the average amount per lamb from the total amount of feed eaten by one lamb in one pen (Šenfelde et al., 2020).

Feed efficiency, Feed conversion rate, Relative growth rate, Kleiber ratio, and residuals: Residual feed intake, Residual weight gain, and Residual intake and live weight gain were calculated (Table 1) using previously published formulas (Berry & Crowley, 2013; Lima et al., 2017). The indicator FE (the amount of weight gain per 1 kg of feed) and FCR (the amount of feed required for 1 kg of weight gain) are inverse to each other; FCR = 1/FE (Lima et al., 2017)

Biochemical analysis

At the end of the fattening or before 24 h fasting before slaughter, body weight measurements and blood samples from the jugular vein were taken from each lamb for hematological and biochemical analysis. Blood samples were taken in the morning before midday. In addition, tests for insulin-like growth factor 1 (IGF-1), insulin, total thyroxine (TT4), adrenocorticotropic hormone, hormone (ACHT), hematocrit (HCT), hemoglobin (Hb), and glucose were performed in a certified laboratory.

Statistiscal analyses

The mean and standard error *(SEM)* were calculated for the measurement data. Appropriate statistical tests *(ANOVA, Kruskal-Wallis, or Median test)* were used to determine the magnitude of the difference between the breed data depending on the normality of the data and/or the homogeneity of the variances. The post hoc tests between the two breeds were used. A significant result was defined as $P < 0.05$. To determine the relationship between the performance of lambs from different Latvian breeds, the relationship index *Eta* (η) was used with limits from 0 (no relationship) to 1 (ideal relationship). *Spearman correlation* was calculated for the total experimental cohort of lambs as several data weren't in the normal distribution. Analytical statistics were performed with SPSS v.25 (IBM Corp., 2017).

Table 1. Traits of Feed efficiency

Traits	Calculated
Feed efficiency, g	$\frac{ADG}{\mathrm{DMI}}$
Feed conversion ratio, kg	$\frac{\mathrm{DMI}}{\mathrm{ADG}/1000}$
Relative growth rate, % day^{-1}	$100 \times \frac{\log \mathrm{BWf} - \log \mathrm{BWi}}{\text{days of fattening}}$
Kleiber ratio	$100 \times \frac{\mathrm{ADG}}{\mathrm{BWf}^{0.75}}$
Residual feed intake, kg day^{-1}	$\mathrm{DMI} - ex\mathrm{DMI}$
Residual weight gain, g day^{-1}	$\mathrm{ADG} - ex\mathrm{ADG}$
Residual intake and live weight gain	$\mathrm{RWG} - \mathrm{RFI}$

ADG – average day gained weight; DMI – dry matter intake; BWi – initial body weight; BWf final body weight RFI – Residual feed intake; RWG – Residual weight gain.

RESULTS AND DISCUSSION

Description of fattening performance

The present study was carried out on an experimental cohort of 76 purebred lambs, the offspring of 22 purebred sire rams: 13 rams from the LT breed, one to three animals each from IF, DOR, MLS, TEX, and CH breeds. Thus, the offspring of sire rams involved in breeding were compared (Table 2).

The lowest rates of ADG were determined for TEX lambs, and the highest was for IF lambs; during the fattening process, all animals had unlimited access to food; however, DMI was statistically different ($P < 0.001$) between breeds. The difference ($P < 0.05$) between the CH breed, whose lambs consumed the least dry matter per day, and the IF breed, with the highest dry matter intake, is 0.67 kg per day.

The values of the average daily weight gain obtained in our study are similar to other studies. Thus, ADG in Belgian TEX lambs is 230 g per day up to the 130th day (Janssens, 2000). According to the study of colleagues from Latvia, the ADG value for the LT breed was 355.7 g (Kairiša & Bārzdiņa, 2016). Dorper lambs weaned at 2–3 months of age gained 0.230 kg per day (Cloete et al., 2000). The difference between the above data and the result of our study is about 100 g. However, it should be considered that different feeding conditions can affect the final gain values (Mahgoub et al., 2000).

Description of feeding efficiency indicators

Feeding efficiency indicators were calculated from AGD and DMI fattening indicators (Table 2). FCR values for lambs range from 4 to 5 kg (for FE in grams from 200 to 250) if a highly concentrated diet is used; from 5 to 6 kg (FE, g, 166.67–200) for a diet from good forage quality; and over 6 kg (> 166.67 g) using lower-quality feed (National Research Council, 2007). The lower the FCR, the less feed is required per 1 kg of weight gain. The lowest mean FCR was determined in our study in DO lambs: 4.21 ± 0.42 kg, and the highest in CH lambs: 5.91 ± 2.13 kg. The results between the breeds were similar when comparing the values of the FCR indicators, as well as FE: in DOR lambs, 1 kg of dry matter accounts for almost 250 g of live weight gain; in IF lambs, the gain was less than 190 g. The value of the FE indicator for DOR lambs was more than for the Doppler and Santa Ins (½:½) crossing breed in Brazil in 2017 (Lima et al., 2017) when it averaged 210 g.

Table 2. Traits of fattening of sheep of Latvian breeds

Traits	All lambs	Breed of sheep*					
		LT [a]	IF [b]	DOR [c]	MLS [d]	TE [e]	CH [f]
Lambs, No	76	48	6	5	8	6	3
ADG, g	330.3 ± 8.1	334.7 ± 10.0	373.5 ± 25.9	359.7 ± 26.00	319.7 ± 22.5	271.0 ± 15.9	272.4 ± 73.5
DMI, kg	1.63 ± 0.02	1.65 ± 0.02 [b,f]	1.97 ± 0.01 [a,c,d,e,f]	1.48 ± 0.11 [b]	1.61 ± 0.03[b,f]	1.45 ± 0.08 [b]	1.30 ± 0.00 [a,b,d]
FE, g	203.1 ± 4.6	202.4 ± 4.9	189.6 ± 13.7	247.2 ± 25.2	197.7 ± 12.7	189.6 ± 14.7	209.8 ± 56.6
FCR, kg	5.13 ± 0.13	5.09 ± 0.14	5.42 ± 0.40	4.21 ± 0.42	5.18 ± 0.26	5.45 ± 0.45	5.91 ± 2.13
RGR, % day^{-1}	0.41 ± 0.01	0.43 ± 0.01	0.41 ± 0.03	0.47 ± 0.01	0.37 ± 0.02	0.32 ± 0.01	0.33 ± 0.07
KR	18.11 ± 0.39	18.46 ± 0.49	20.09 ± 1.13	20.40 ± 0.52	16.77 ± 0.88	14.80 ± 0.51	14.83 ± 3.06
RFI, kg day^{-1}	0.00 ± 0.02	0.01 ± 0.02 [b]	0.29 ± 0.04 [a,c,d,e,f]	-0.21 ± 0.10 [b]	0.02 ± 0.03 [b]	-0.09 ± 0.08 [b]	-0.25 ± 0.07 [b]
RWG, g day^{-1}	0.00 ± 5.7	5.1 ± 6.9 [c]	-16.00 ± 19.7 [c]	70.1 ± 14.8 [a,b,d,e]	-35.2 ± 13.8 [c]	-36.9 ± 14.7 [c]	2.1 ± 21.5
RIG	0.00 ± 0.20	0.05 ± 0.19 [b,c]	-2.00 ± 0.62 [a,c,f]	2.64 ± 0.89 [a,b,d,e]	-0.83 ± 0.41 [c]	-0.23 ± 0.76 [c]	1.52 ± 0.86 [b]

Breeds of sheep: LT – Latvian dark-head; IF – Île de France; DO – Dorper; MLS – Merinolandschaf; TE – Texel; CH – Charollais. ADG – average day gained weight; DMI – dry matter intake; FCR – Feed conversion ratio; FE – Feed efficiency; RGR – Relative growth rate; KR – Kleiber ratio; RFI – Residual feed intake; RWG – Residual weight gain; RIG – Residual intake and body weight gain; *subscript letters (shown by breed) indicate the variety with which there is a statistically significant difference of post hoc test of ANOVA or Kruskal-Wallis/Median.

There are few publications directly devoted to the feeding efficiency indicator. FCR indicator, the most commonly used in feeding efficiency trait analysis for our lambs, ranges from 3.79 kg for DOR lambs to 13.88 kg for SA lambs. A similar trend is observed when comparing the average values of the FCR of lambs from Latvian breeds with data from other breeds (Lima et al., 2017; Tortereau et al., 2020; Mupfiga et al., 2022). According to study of the Romane breed, the value of the FCR heritability index is 0.30. Thus, this breed has great potential for genetic improvement relative to this indicator (Tortereau et al., 2020).

The next two indicators of feeding efficiency are ratios indicators of growth efficiency: Relative growth rate (RGR) (Berry & Crowley, 2013) and the Kleiber ratio (KR), which provides a measure of growth efficiency independent of body size (Köster et al., 1994). According to our data, DOR lambs have the highest average RGR and KR values, while TEX lambs, in turn, have the lowest (Table 2). Thus, DOR lambs with the lowest body weight on the 90th day have the highest growth efficiency among the lambs from other breeds.

The RGR data of lambs, fattened in the current study, are similar to those reported for other breeds from weaning to six months of age (Kesbi & Tari, 2015; Lima et al., 2017; Ghafouri-Kesbi & Eskandarinasab, 2018; Ehsaninia, 2022), thus proving the competitiveness of Latvian sheep breeds.

The KR values calculated in this study for DOR, IF and LT breeds were significantly higher at the corresponding lambing age, relative to other sheep breeds (Talebi, 2012a; Kumar et al., 2017; Venkataramanan et al., 2019; Bansal et al., 2021; Bukhari et al., 2022; Ehsaninia, 2022) or were similar (Lima et al., 2017). Therefore, a higher KR value indicates greater weight gain for the same metabolic body weight ($BW^{0.75}$), i.e., without increasing energy consumption (Talebi, 2012b). On the contrary, the KR value was lower for the MSL, TEX, and CH breeds.

The FE scores are residuals for the feed efficiency tract (Table 2): Residual Feed Intake (RFI), Residual Gain (RWG), and their sum, or Residual Feed Intake and Body Weight Gain (RIG). The RFI is the most frequently analyzed quantity and is of great economic importance, allowing the detection of an animal consuming less than the planned amount of feed, thus reducing costs (Berry & Crowley, 2013). In turn, the RWG indicator shows which animal gained more / less weight than planned, taking into account the amount of food consumed; it allows to identify of fast-growing animals with the highest ADG and the lowest DMI, consuming less food than the average for the population, without differences in BW. The higher the RGI, the better the ratio between ADG and DMI (Lima et al., 2017).

The average calculated RFI statistically significantly ($P < 0.001$) differs between DOR and IF breeds, within -0.21 ± 0.10 kg day^{-1} for the DOR breed and 0.29 ± 0.04 kg day^{-1} for the IF, respectively. Thus, IF lambs consume, on average, more dry matter than DOR lambs.

Statistically significant differences between breeds in our study were also determined by calculating the values of the RWG indicator - a positive mean was found for the DOR, LT, and CH lambs, but negative for the other breeds. Thus, according to the results obtained, DOR, LT and CH breed lambs have a higher body weight at the end of fattening in accordance with the metabolic weight and DMI used, but for the other four breeds, the values of these indicators were lower.

Our results show that RIG is positive for LT, DOR, and CH breeds but negative - for IF, MLS, and TEX ($P < 0.001$; $\eta = 0.57$).

According to our data, lambs of the DOR breed have improved average values for all the above indicators of feeding efficiency trait; the second place is occupied by lambs of the LT breed regarding the quality of the studied parameters. The lowest result was presented in the analyzed group of CH and IF breeds lambs.

When analyzing the data obtained in the current study, we consider that the study was conducted in an experimental cohort of lambs. Thus, the obtained results and statistical conclusions from the data received can't be accepted for all Latvian breeds in general, because in the case of IF, DOR, MLS, TEX, and CH breeds offspring of 1 to 3 rams were used. Therefore, to create a permanent analysis of the breeds raised in Latvia, it would be necessary to analyze all breeds of lambs over several years.

Description of hematological and biochemical parameters

The level of hematological and biochemical parameters in the blood of lambs was determined at the end of fattening at about five months of age of animals, to identify individual characteristics for each of the studied breeds (Dias et al., 2010). According to early studies, hematological blood parameters: hematocrit and hemoglobin values are less variable over time (Ullrey et al., 1965), but biochemical parameters: IGF-1, insulin, TT4, ACTH, and glucose are more dependent on feed composition (Mahgoub et al., 2015).

A statistically significant difference between breeds grown in Latvia was found for three biochemical parameters (Table 3): IGF-1 ($P < 0.001$; $\eta = 0.56$), insulin ($P < 0.05$; $\eta = 0.22$) and glucose ($P < 0.001$; $\eta = 0.69$).

Table 3. Hematological and biochemical analysis of sheep of breeds of Latvia

Traits	Norm	All lambs	Breed of sheep *					
			LT [a]	IF [b]	DOR [c]	MLS [d]	TEX [e]	CH [f]
IGF-1, ng ml^{-1}	n.d.	198.68 ± 7.80	191.43 ± 9.99 [b,c,e]	254.17 ± 10.31 [a,e]	257.20 ± 11.36 [a,e]	238.00 ± 11.18 [e]	118.00 ± 8.39 [a,b,c,d]	125.00 ± 22.61
Insulin, mU l^{-1}	n.d.	0.75 ± 0.06	0.80 ± 0.09	0.92 ± 0.10	0.60 ± 0.04	0.69 ± 0.14	0.58 ± 0.04	0.40 ± 0.00
TT4, nmol l^{-1}	38.6 – 77.2$	67.90 ± 4.50	61.86 ± 5.38 [a]	93.33 ± 7.06 [b]	54.10 ± 21.00	70.49 ± 18.40	94.00 ± 14.14	72.67 ± 10.11
ACTH, pg ml^{-1}	50 – 100#	76.135 ± 8.50	70.45 ± 11.32	66.73 ± 14.21	112.06 ± 48.25	71.91 ± 15.02	102.22 ± 32.13	105.63 ± 33.20
HCT, %	27.0 – 45.0$	24.72 ± 0.79	23.44 ± 0.83	23.50 ± 1.82	22.80 ± 1.16	30.13 ± 2.82	26.33 ± 4.14	31.67 ± 7.26
Hb, g l^{-1}	90.0 – 150.0^	125.72 ± 1.24	127.28 ± 1.33	130.50 ± 4.33	121.00 ± 8.24	115.50 ± 3.47	127.83 ± 4.13	121.00 ± 4.58
Glucose, mmol l^{-1}	2,78 – 4,44$	4.14 ± 0.06	3.96 ± 0.06 [b]	5.23 ± 0.17 [a,c,d,e]	4.50 ± 0.26 [b]	4.29 ± 0.15 [b]	3.89 ± 0.12 [b]	4.03 ± 0.05 [b]

Breeds of sheep: LT – Latvian dark-head; IF – Île de France; DOR – Dorper; MLS – Merinolandschaf; TEX – Texel; CH – Charollais. IGF-1 – Insulin-like growth factor-1; TT4 – Total thyroxine; ACTH – Adrenocorticotropic hormone; HCT – hematocrit; Hb – hemoglobin; * subscript letters (shown by breed) indicate the variety with which there is statistically significant difference of post hoc test of ANOVA or Kruskal-Wallis/Median. #Amokrane-Ferrah et al., 2022; ^Latimer 2011; $Dias et al., 2010.

IGF-1 is a growth hormone-dependent peptide that, in its unbound form, has a very short - 4 min in sheep biological half-life (Bruce et al., 1991) and is involved in a variety of physiological processes: cell proliferation, embryogenesis, tissue repair, and the metabolism of carbohydrates, proteins, and lipids to stimulate bone and skeletal muscle pre- and post-natal growth as well as in lipolysis and mammary gland development (Flores-Encinas et al., 2021).

The average level of insulin-like growth factor-1 in lambs of three breeds LT, TEX, and CH was significantly lower compared to other Latvian breeds, as well as compared to the level of this hormone in DOR sheep (209.2/375.9 ng mg^{-1}; Flo; Tarazi et al., 2014). Interestingly, the average IGF-1 level in healthy Awassi sheep from this population was around 145 ng mL^{-1}, a value close to that we determined for LT, TEX, and CH lambs. The level of IGF-1 hormone depends on the breed's genomic differences and other intrinsic features, so its laboratory reference level is not established. Plasma levels of IGF-1 have also been found to differ in sheep with different alleles of the two SNPs in the IGF-1 gene promoter on the same diet (Flores-Encinas et al., 2021).

There is also no specific norm for the insulin level in sheep's blood. In the present study, differences were found in the average level of insulin in the blood of lambs of various Latvian breeds. Thus, LT and IF lambs have a higher average level of insulin, in turn, the lowest level was determined for lambs of the CH breed.

The hormones insulin and glucose analyzed in this study are jointly involved in energy metabolism; insulin promotes the breakdown or conversion of glucose into energy (Norton et al., 2022). Thus, we can assume a relationship between their levels, which was not observed in the present study: the lowest average insulin level was noted for CH lambs, and the lowest average glucose level for TEX lambs. In ruminants (Catunda et al., 2013), due to microbial activity in the rumen, the absorption of carbohydrates in the form of hexose sugar in the small intestine is insignificant or absent. For this reason, volatile fatty acids (propionate and butyrate) stimulate insulin secretion more effectively than glucose.

A laboratory standard for glucose is known: 2.78–4.44 nmol L^{-1}. When comparing the average values of this hormone in the blood of the analyzed IF and DOR lambs, it was determined to be higher than the established norm, considering the same feeding conditions. In addition, these breeds had the highest and lowest DMI, respectively. Thus, it can be assumed that in addition to the conditions and composition of feeding, another mechanism that affects insulin levels. The relationship between glucose levels with reduced and increased body weight in sheep breeds has been analyzed (Francis et al., 1999), but unequivocal conclusions have not been drawn.

No difference was found between the levels of other hematological and biochemical indicators between breeds, however, marked differences from their reference values were found, except for Hb. TT4 was above normal for IF and TEX breeds; the ACTH level had higher average values for DOR, TEX, and CH breeds.

In the present study, hematocrit levels were found below the reference value of this hematological blood parameter in LT, IF, DOR, and TEX lambs. In addition, the HCT values outside (mostly below) the normal range have also been reported for different species; levels below 24 are considered in sheep as an indicator of susceptibility to anemia (Seixas et al., 2021); however, it should be taken into account that the reference values of blood parameters of different sheep breeds may differ significantly.

Correlation between indicators

In order to analyze the relationship between feed efficiency and hematological/ biochemical indicators, correlation analysis was carried out for all lambs from the experimental cohort (Fig. 1).

According to the results obtained, very tight or high correlations were found between all indicators of feed efficiency. Furthermore, according to studies in other sheep populations, Kermani lambs also showed a phenotypic correlation between RGR and KR indicators (Ehsaninia 2022); in the breeds INRA401 (Bibé et al., 2007), Romane

(Tortereau et al., 2020) and Hu (Zhang et al., 2017), correlations between FCR and RFI were determined; a negative correlation between FCR and KR was found in Lori-Bakhtiar lambs, as well as in various breeds of cows (Talebi, 2012b).

Traits	FE	FCR	RGR	KR	RFI	RWG	RIG	IGF-1	Insulin	TT4	ACTH	HCT	Hb
FCR	**-0.94**												
RGR	**0.74**	**-0.74**											
KR	**0.75**	**-0.76**	**0.97**										
RFI	**-0.56**	**0.44**	-0.07	0.01									
RWG	**0.78**	**-0.70**	**0.85**	**0.82**	**-0.46**								
RIG	**0.78**	**-0.67**	**0.54**	**0.47**	**-0.86**	**0.86**							
IGF-1	**0.45**	**-0.48**	**0.55**	**0.63**	0.10	**0.44**	0.20						
Insulin	0.14	-0.16	0.14	0.14	0.00	0.08	0.05	0.18					
TT4	-0.05	0.02	-0.18	-0.14	-0.10	-0.10	0.00	**-0.26**	-0.02				
ACTH	0.07	0.03	-0.09	-0.09	**-0.22**	0.06	0.16	-0.15	0.16	0.13			
HCT	0.06	-0.01	-0.05	-0.04	-0.07	-0.04	0.02	-0.04	-0.03	-0.14	0.01		
Hb	0.20	**-0.22**	0.19	0.19	-0.01	0.12	0.07	0.01	0.11	0.05	-0.01	**0.21**	
Glucose	0.10	-0.11	**0.23**	**0.35**	**0.23**	**0.23**	0.00	**0.44**	0.10	**0.21**	-0.02	0.05	-0.08

Figure 1. Correlation of feed efficiency and hematological/biochemical indicators for lambs of all breeds. FCR – Feed conversion ratio; FE – Feed efficiency; RGR – Relative growth rate; KR – Kleiber ratio; RFI – Residual feed intake. RWG – Residual weight gain; RIG – Residual intake and body weight gain; GF-1 – Insulin-like growth factor-1; TT4 – Total thyroxine; ACTH – Adrenocorticotropic hormone; HCT – hematocrit; Hb – hemoglobin. Value with statistical significance $P < 0.05$ is highlighted in bold.

As a result of the analysis of hematological and biochemical parameters in the blood of lambs, a medium direct correlation was determined between IGF-1, TT4, and glucose; a statistically significant correlation was also found between Hb and HCT.

Thus, one of the objectives of this study was to elucidate the relationship between the indicators of feed efficiency and hematological and biochemical parameters of the blood of lambs. According to the results obtained, IGF-1 and Glucose have a statistically significant correlation with feed efficiency indicators in a joint analysis of all lambs from the experimental cohort; the same level of correlation was also determined between ACTH and the RFI indicator.

According to published data, Hu lambs with low RFI values had lower TT4 and ACTH values and a positive correlation between these parameters; a positive correlation between FCR and TT4 indicators was also found in this breed (Zhang et al., 2017).

CONCLUSIONS

According to the results of our study, the breeds of sheep raised in Latvia differ in feed efficiency and hematological and biochemical parameters. The highest feed efficiency values were found in offspring from two sire rams of the DOR breed, and the lowest values were in offspring from two sire rams of the CH and IF breeds. Accordingly, it would be advisable in future studies to determine the genetic determinants of these differences since IF animals are superior in terms of body weight and ADG value.

Our results prove the differences between the studied Latvian sheep breeds regarding of the hematological and biochemical parameters levels. In the context of this study, the question arises whether these levels directly or indirectly affect indicators of feed efficiency. At the same time, it is necessary to continue research on reference norms in different breeds since our data showed that healthy lambs' hematological and biochemical parameters could be either higher or lower than laboratory-established reference norms. By obtaining information about the norms of breeds grown in Latvia, it is possible to improve sheep veterinary knowledge.

The correlation between the feed efficiency indicators and biochemical parameters of the blood of lambs shows the possibility of hormonal influence on feed efficiency traits in Latvian sheep breeds. Therefore, by using the acquired knowledge in fattening lambs, it is possible to improve feed efficiency and increase the amount of meat obtained by correcting hormonal levels.

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