Physiology of digestion in productive animals

UDC 636.3:636.082.266:591.13:612.015.3

doi: 10.15389/agrobiol.2016.4.500rus

doi: 10.15389/agrobiol.2016.4.500eng

BIOLOGICAL PARAMETERS FOR DIGESTIVE AND METABOLIC PROCESSES IN INTERSPECIES HYBRIDS OF DOMESTIC SHEEP (*Ovis aries*) AND ARGALI (*Ovis ammon polii*)

N.V. BOGOLYUBOVA, V.N. ROMANOV, V.A. DEVYATKIN, I.V. GUSEV,
V.A. BAGIROV, N.A. ZINOVIEVA

L.K. Ernst All-Russian Research Institute of Animal Husbandry, Federal Agency of Scientific Organizations, pos. Dubrovitsy, Podolsk Region, Moscow Province, 142132 Russia, e-mail 652202@mail.ru

Acknowledgements:

Supported financially by Russian Scientific Foundation (project number 14-36-00039)

Received April 30, 2016

Abstract

Introduction of the allele pool of wild species, in particular, Argali (*Ovis ammon polii*) into the domestic sheep (*Ovis aries*) of the modern breeds is one of the promising approaches to enhancing genetic diversity and, consequently, biodiversity and nutrient availability. Study of the processes of digestion, assimilation of nutrient substrates in the body and metabolism is the basis for developing the feeding systems for animals of the novel genetic variation. The objective of this survey was to study and metabolism, digestibility, and nutrient requirements of hybrids of Romanov sheep and Argali. The experiments were performed on the wethers fitted with rumen fistulas (Vivarium of the L.K. Ernst Institute for Animal Husbandry, Moscow Province, pos. Dubrovitsy) in 2014-2015. The experimental animals were divided into three groups. Group I (control) included the purebred Romanov sheep (ROM, $n = 3$), group II included the F₃ hybrids (HYB1, $n = 3$) from crossing Romanov ewes with F₂ hybrid Romanov ewes and Argali (87.5 % of the Romanov sheep blood and 12.5 % of the Argali blood), and group III included the F₃ hybrids (HYB2, $n = 3$) from crossing F₂ hybrids Romanov ewes and Argali with the Edilbaj sheep (50 % of the Edilbaj sheep blood, 37.5 % of the Romanov sheep blood, and 12.5 % of the Argali blood). The rumen content and blood samples for the analysis were taken an hour before feeding and in three hours after feeding. The production of volatile fatty acids (VFAs) (using Markham distillation apparatus), the amount of ammonia-N (by the Conway microdiffusion method), amylolytic activity (photometrically), the protozoa and bacteria biomass (by centrifugation) have been measured in rumen. Hemoglobin concentration, red blood cell count and white blood cell count were determined. The levels of total protein, albumin, globulin, urea, creatinine, alanine aminotransferase (ALT), aspartate aminotransferase (AST) activity, glucose, cholesterol were estimated in blood serum. The ruminal fermentation in the hybrid animals, when compared to the purebred animals, was more active; it could be confirmed by the higher total microbial mass in hybrid animals (+37.0 % and +37.3 %, respectively, before feeding; +22.2 % and +33.3 %, respectively, after feeding), the VFA increased concentration (+17.5 % and +26.1 %, respectively, before feeding; +8.7 % and +12.0 %, respectively, after feeding), the increased amylolytic activity in rumen fluid (+10.3 ...+14.0 %), and the decreased ammonia concentrations (−8.4...−27.7 %). Intensified fermentation caused the better nutrient digestibility and utilization in hybrid animals. The HYB1 sheep, when compared to the control group, were characterized by the better digestibility of dry matter (+7.8 %), organic matter (+5.3 %), crude protein (+6.9 %), crude fat (+3.8 %, $p < 0.05$), crude fiber (+6.5 %, $p < 0.05$), and the nitrogen free extractable substances (NFE) (+4.5 %). The nitrogen utilization coefficient in the ROM group comprised 27.9 %, which is 8.9 % and 8.5 % less than that in the animals of the HYB1 group and the HYB2 group, respectively. The differences in the concentrations of both the carbohydrate and lipid metabolites and the nitrogen metabolites between the groups of purebred and hybrid sheep were ascertained. The analysis of blood metabolic profiles revealed the higher concentrations of glucose and creatinine, the higher albumin to globulin ratio, and the reduced cholesterol level in the hybrid animals compared to the purebred Romanov sheep. Therefore, the obtained data indicate that the metabolic processes are more intense in the hybrids than that in the purebred sheep. The data obtained can serve as a basis for developing the physiologically sound feeding programs for animals of the novel genetic variation to realize the maximum potential productivity.

Keywords: ruminant animals, hybrid animals, ruminal digestion, fermentative processes, digestibility, metabolism

One of the ways to improve livestock productivity and the quality of the final products is to introduce the wild species resources into the agricultural production by creating new forms of animals by interspecific hybridization [1-3].

Artificial hybridization of different species of *Ovis* has long attracted researchers. Thus, M.Ph. Ivanov, used a moufflon to develop a new sheep breed called the mountain merino, which was suitable for year-round husbandry on the mountain pastures [4]. P.A. Manteuffel suggested an idea of creating Nordic sheep by hybridization with bighorn sheep [5], which later found its way in the works of other researchers [6, 7]. A new breed of fine-wool sheep for meat and wool called Kazakh Arkhar-Merino was produced by hybridization between a Marco Polo's sheep (*O. ammon polii*) and a fine-wool sheep [8]. Hybridization of Karakul ewes with Argali resulted in a gray subspecies of Karakul sheep [9]. The introduction of the allele pool of wild species into domestic animals is one of the promising approaches to enhancing nutritional diversity [10] and providing people with safe and healthy food. In this respect, revealing morphological, physiological and biochemical mechanisms that regulate digestion processes and contribute to the establishment of productive qualities in animals with new genotypes is of particular importance [11-13].

At L.K. Ernst All-Russian Research Institute of Animal Husbandry (RIAH) the projects on developing new interspecific hybrids between Romanov sheep (*Ovis aries*) and Argali (*Ovis ammon*) are underway, aimed to create new breeding forms with modified nutrient composition [14], combining the desirable performance and biological traits with the adaptive potential of the parent species. For example, Romanov sheep are characterized by outstanding productive qualities and multiple pregnancy, but a low resistance and a certain softness of the constitution [15]. Mountain sheep (Argali), the largest wild sheep, is relatively unpretentious and able to survive in extremely adverse environmental conditions [16].

It is known that the activity of regulatory systems depends on genotypic characteristics, which is accompanied by variations in the intensity of specific digestive and metabolic processes. Digestibility and utilization of nutrients, as well as nutritional requirements are unequal in animals of different origin [17, 18]. Due to the differences in the adaptive potential of the digestive apparatus in animals with different genotypes, specific conditions are being developed in their gastrointestinal tract that affect the activity of microorganisms and the biosynthesis of metabolites [19-23]. Understanding the underlying regulation of these processes is essential to justify the reasonable feeding of livestock and improve feed efficiency [24-25].

In addition, determination of parameters characterizing the digestion, absorption of nutritious substrates in the body and metabolism is one of the mandatory requirements in developing feeding regimes for newly bred animal forms [26-29]. Accounting for their physiological and biochemical status allows optimizing the diets that ensure the most complete realization of high productivity potential achieved as a result of breeding [30].

In this paper, for the first time we compared a number of biological parameters pertinent to digestive and metabolic processes in developed interspecific hybrids between domestic sheep (*Ovis aries*), with the Romanov breed or Romanov and Edilbaev breeds involved, and Argali (*Ovis ammon polii*). In this, a more extensive turnover and better absorption of nutrients in these sheep as compared to similar animals of the Romanov breed have been revealed.

Our objective was to evaluate and compare the digestion, metabolism,

digestibility and utilization of dietary substrates in the purebred Romanov sheep vs. different hybrids resulted from crossing domestic sheep with Argali.

Technique. Investigations were performed under conditions physiological yard (RIAH, 2014-2015), using three groups of wethers of different origin, age- (6-7 months) and body weight-matched, with rumen fistulas implanted (by Basov). Group I (control) included the purebred Romanov wethers (ROM), group II included the F₃ hybrids (HYB1) from crossing Romanov ewes with the Romanov ewe and Argali F₂ hybrid (87.5 % of the Romanov sheep blood and 12.5 % of the Argali blood), and group III consisted of the F₃ hybrids (HYB2) from crossing the Romanov ewe and Argali F₂ hybrids with rams of the Edilbaev sheep (12.5 % of the Argali blood, 37.5 % of the Romanov sheep blood, and 50 % of the Edilbaev sheep blood). All animals were fed with a combined diet, customized based on the RIAH regulations [31] for the young Romanov sheep, which consisted of silage, haylage, hay and concentrates.

The investigations were conducted for 28 days. A preliminary stage lasted 21 days, followed by 7-day record period. Total moisture content, crude fat (by S.V. Rushkovsky), crude protein (by Kjeldahl method) and crude fiber levels (by Henneberg and Sttohmman) were measured in collected samples of feed, feed residues and feces. The nitrogen amount was evaluated in the urine. Based on the findings revealed in the digestible trial, the amount and digestibility of nutrient, and nitrogen intake were calculated using the conventional methods [32].

The rumen fluid samples and blood samples were collected 1 hour before and 3 hours after the morning feeding.

The following parameters were measured in the rumen contents: total amounts of volatile fatty acids (VFAs) by steam distillation (using Markham micro-distillation apparatus), the amount of ammonia-N by the Conway micro-diffusion method, amylolytic activity (photometrically), and protozoal and bacterial biomass by differential centrifugal sedimentation (using Sigma 3-18 centrifuge, Germany) [33].

The following parameters were measured in the rumen contents: total amounts of volatile fatty acids (VFAs) by steam distillation (using Markham micro-distillation apparatus), the amount of ammonia-N by the Conway micro-diffusion method, amylolytic activity (photometrically), and protozoal and bacterial biomass by differential centrifugal sedimentation (using Sigma 3-18 centrifuge, Germany) (33)

Blood test including hemoglobin concentrations, red blood cells and white blood cells counts was performed using a Micros ABC VET (HORIBA ABX Diagnostics, Inc., France) veterinary hematology analyzer. Blood levels of total protein, albumins, globulins, urea, creatinine, glucose, cholesterol, alanine aminotransferase activity (ALT), aspartate aminotransferase (AST) were evaluated using a Chem Well 2902 (+) (Awareness Technology, Inc., USA) automated chemistry analyzer [34].

Statistical analysis was performed, using the Microsoft Excel [35].

Results. The digestion in the rumen of ruminants mainly depend on its microflora activity, moreover, they influence the efficiency of energy and feed nutrients use. It is the rumen environment where proteins are cleaved, amino acids processed, ammonia formed, bacterial protein synthesized, non-protein nitrogen compounds absorbed and excreted. Microbial fermentation of the feed in the forestomachs results in the formation of volatile fatty acids (VFAs), amino acids and ammonia [36].

We found that a higher total mass of symbiotic microorganisms contained in the rumen fluid in HYB1 and HYB2 animals indicated a more extensive microbial activity in the forestomachs of hybrid sheep (Fig. 1). In these

groups, the parameter under investigation was lower before feeding than after it was initiated. The symbiotic microflora biomass in group II (HYB1) before and after feeding was 37.3 and 33.3 % higher ($p < 0.05$), respectively, and in group III (HYB2) it was 37.0 and 22.2 % higher than in the control (ROM). It should be noted that the microbial mass elevated mainly due to the increased number of bacteria. In the HYB1 animals, the levels before and after feeding were increased by 62.6 % ($p < 0.05$) and 48.3 % ($p < 0.05$), respectively, and in the HYB2 animals by 46.3 ($p < 0.05$) and 28.0 %, respectively, compared to those in the ROM. The highest difference vs control was seen in the HYB1 hybrids. Elevations in the symbiotic microflora counts resulted in increased digestibility of the nutrients and a better utilization of nitrogen by the rumen microflora.

Fig. 1. Microbial biomass composition in the rumen fluid in the purebred Romanov sheep (a), the F₃ hybrids of Romanov sheep × Argali (*Ovis ammon polii*) (b), and the F₃ hybrids of the Romanov sheep × Argali with rams of the Edilbaev breed (c) before and after feeding: 1 — bacteria, 2 — protozoa, 3 — total microorganism counts (L.K. Ernst All-Russian Research Institute of Animal Husbandry, Moscow Province, 2014–2015).

Fig. 2. The amount of volatile fatty acids (mmol/100 ml) (1) and ammonia-N (mg%) (2) in the rumen fluid in the purebred Romanov sheep (a), the F₃ hybrids of Romanov sheep × Argali (*Ovis ammon polii*) (b), and the F₃ hybrids of the Romanov sheep × Argali with rams of the Edilbaev breed (c) before and after feeding (L.K. Ernst All-Russian Research Institute of Animal Husbandry, Moscow Province, 2014–2015)

17.5 ($p < 0.05$) and 8.7 % ($p < 0.05$) in group III, indicating the more extensive hydrolysis of carbohydrates.

The utilization of starch and other fast-acting carbohydrates in the rumen is a prerequisite for the maintenance of normal vital activity of the microflora. Amylolytic activity of the rumen fluid is ensured by microorganisms, as well as by the availability of free amylase [38]. In the HYB2 and HYB1 groups, these levels were higher by 14.0 % ($p < 0.05$) and 10.3 %, respective-

VFAs are highly valuable macronutrients, from which lipoproteins and carbon skeletons of almost all amino acids are synthesized [37]. In our investigations a total amount of VFAs in the rumen fluid increased after feeding in all animals (Fig. 2). In hybrid animals compared to purebred Romanov sheep, the level of these metabolites were higher before and after feeding by 26.1 % and 12.0 % ($p < 0.05$), respectively in group II (HYB1), and by

ly, than in the ROM.

Ammonia, the final product of cleavage proteins and non-protein nitrogen compounds in the feed, plays an important role in the conversion of nutrients in the rumen. Some ammonia is absorbed into the bloodstream from the digestive tract, and this is a useless loss of nitrogen, since just a small part of it appears back into the rumen through the saliva and the rumen wall, while most of it is removed from the body in the urine [39, 40]. Our investigations (Fig. 2) have demonstrated a decrease in the concentrations of ammonia-N in the rumen fluid in hybrid animals ($p < 0.05$) after feeding and compared to the control, as well as lower blood levels of urea (see Table) that may indicate a more efficient use of nitrogen by the rumen microflora.

Blood levels of protein, carbohydrate and lipid metabolites in purebred Romanov sheep and their hybrids with Argali (*Ovis ammon polii*) and rams of the Edilbaev breed ($M \pm m$, L.K. Ernst All-Russian Research Institute of Animal Husbandry Moscow Oblast, 2014-2015)

Parameter	Group					
	I ($n = 3$)		II ($n = 3$)		III ($n = 3$)	
	before feeding	after feeding	before feeding	after feeding	before feeding	after feeding
Total protein, g/l	68.2±0.85	68.8±1.23	70.5±0.50*	70.7±0.54	68.6±1.06	69.4±1.49
Urea, mmol/l	5.03±0.20	6.89±0.14	5.03±0.18	6.70±0.30	4.89±0.23	6.66±0.41
Creatinine, μmol/l	61.40±3.05	66.92±1.30	76.90±3.60*	78.11±0.70***	68.80±4.10	69.20±2.50
Albumins, g/l	28.9±0.26	30.4±0.34	30.9±0.70*	32.5±0.43**	29.9±0.63	31.5±0.46
Globulins, g/l	39.2±0.86	38.4±1.14	39.6±0.78	38.2±0.34	38.7±0.65	37.9±1.20
A/G	0.74±0.02	0.79±0.02	0.78±0.02	0.85±0.01	0.77±0.01	0.83±0.02
ALT, IU/l	17.0±0.60	16.9±0.35	17.1±0.60	17.2±0.70	17.9±0.63	18.9±0.50*
AST, IU/l	72.9±2.50	76.0±2.84	63.7±3.80	68.3±2.18	84.2±2.65*	84.8±3.60
Glucose, mmol/l	4.56±0.07	4.85±0.08	4.83±0.09*	4.99±0.10	5.45±0.09***	5.63±0.04***
Cholesterol, mmol/l	1.64±0.04	1.54±0.04	1.44±0.04*	1.32±0.03**	1.37±0.04**	1.37±0.03*

Note. Group I (control) — the Romanov wethers, group II — the F₃ hybrids from crossing Romanov ewes with the Romanov sheep and Argali F₂ hybrid (87.5 % of the Romanov sheep blood and 12.5 % of the Argali blood), group III — the F₃ hybrids from the Romanov ewe and Argali F₂ hybrids crossed with the Edilbaev sheep (50 % of the Edilbaev sheep blood, 37.5 % of the Romanov sheep blood, and 12.5 % of the Argali blood). Blood samples were collected 1 hour before feeding and 3 hours after feeding, A/G — albumin to globulin ratio, ALT — alanine aminotransferase, AST — aspartate aminotransferase.

*, **, *** Differences compared to the control (group I) are significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively.

Changed character of the processes in the forestomachs of animals which depends on their origin affected the digestion of different feed nutrients. In the HYB1 animals, digestibility coefficients of dry matter, organic matter, crude protein, crude fat, crude fiber and nitrogen-free extractives were 7.8 %, 5.3 %, 6.9 %, 3.8 % ($p < 0.05$), 6.5 % ($p < 0.05$) and 4.5 % higher than those in the ROM. The HYB2 animals also demonstrated increases in these parameters vs. control.

The studied groups were characterized by differences in the use of dietary nutrients. The amount and percentage of nitrogen digested and deposited in the body were higher in the hybrid animals, despite a slight increase in its content in the feces (group III) and urine (group II). The nitrogen utilization coefficient in the ROM group (control) was 27.9 %, which was 8.9 % and 8.5 % less than that in the HYB2 and HYB1 animals. Blood tests in the hybrid animals demonstrated higher total protein, decreased urea, increased albumin-globulin ratio (see Table), which might indicate higher protein metabolism.

Hybrid animals vs ROMs demonstrated significantly increased blood glucose levels (see Table), which confirmed that microbial biomass was more extensively carried through the forestomach into the intestine. Thus, in the HYB1 animals this parameter was 2.8-5.9 % ($p < 0.05$) higher, and in the HYB2 16.0-19.5 % ($p < 0.001$) higher in comparison to the control. On the contrary, the cholesterol levels in group I were the highest and exceeded those in groups II and III by 0.20-0.22 mmol/l ($p < 0.05$, $p < 0.01$) and 0.17-0.27 mmol/l ($p < 0.05$, $p < 0.01$), respectively.

Fig. 3. Blood levels (%) of red blood cells (1), white blood cells (2) and hemoglobin (3) in the purebred Romanov sheep (the line), the F₃ hybrids of Romanov sheep and Argali (*Ovis ammon polii*) (a) and the F₃ hybrids of the Romanov sheep × Argali with rams of the Edilbaev breed (b) after feeding (L.K. Ernst All-Russian Research Institute of Animal Husbandry, Moscow Oblast, 2014-2015).

es the energy potential of the cells) appeared to be substantially higher in hybrid animals compared to the purebred ones. Its values before and after feeding in group II exceeded those in the control by 25.2 % ($p < 0.05$) and 16.7 % ($p < 0.001$), and in group III by 12.0 % and 3.4 %, respectively.

The hybrid animals showed higher levels of red blood cells (by 0.8-2.9 %) concurrent to a decrease in white blood cells by 21.8% ($p < 0.05$) (Fig. 3). The hybrids in group III vs. their purebred counterparts also demonstrated higher hemoglobin concentrations (by 9.6 %, $p < 0.01$). These findings indirectly suggest that hybridization has had a generally beneficial effect on the general physiological condition of the animals.

Thus, the obtained hybrids of domestic sheep and Argali having different blood relationship (12.5 % of Argali and 87.5 % of Romanov breed; 12.5 % of Argali, 37.5 % of Romanov breed and 50.0 % of Edilbaev breed) demonstrated an increase in ruminant digestion rates, exemplified by elevated symbiotic microflora biomass, increased amounts of volatile fatty acids and amylolytic activity of the rumen contents, as compared to the purebred Romanov sheep. Consequently, digestibility, nutrient utilization, trends in protein, carbohydrate and lipid metabolism in the hybrids and their purebred counterparts also differ. The identified physiological features of new bred forms should be always considered in order to develop standardized requirements and feeding patterns, which will allow to realize genetic potential for productivity in the hybrids. .

REFERENCES

1. Ernst L.K., Zinov'eva N.A. *Biologicheskie problemy zhivotnovodstva v XXI veke* [Biological aspects of livestock husbandry in XXI]. Moscow, 2008 (in Russ.).
2. Bagirov V.A., Ernst L.K., Nasibov Sh.N., Klenovitskii P.M., Iolchiev B.S., Zinov'eva N.A. *Dostizheniya nauki i tekhniki APK*, 2009, 7: 54-56 (in Russ.).
3. Nasibov Sh.N., Bagirov V.A., Klenovitskii P.M., Iolchiev B.S., Zinov'eva N.A., Voevodin V.A., Amirshoev F.S. *Dostizheniya nauki i tekhniki APK*, 2010, 8: 59-62 (in Russ.).
4. Rokitskii P.F., Vasina-Popova E.T. *Razvitie genetiki sel'skokhozyaistvennykh zhivotnykh v SSSR: Istoriko-biologicheskie issledovaniya. Vyp. 6* [The development of farm animal genetics in the Soviet Union: History and biological research. Iss. 6]. Moscow, 1978 (in Russ.).
5. Manteifel' P.A. *Rekonstruktsiya fauny i odomashnivanje novykh vidov zhivotnykh* [Fauna — reconstruction and domestication]. Moscow, 1934 (in Russ.).
6. Nasimovich A.A. *Zoologicheskii zhurnal*, 1961, 40(7): 957-970 (in Russ.).
7. Shaidullin I.N. *Otvsevodstvo*, 1992, 3: 18-21 (in Russ.).

Nitrogen metabolism in the HYB1 animals vs. ROM was characterized by the following features: there was a slight increase in total protein ($p < 0.05$), albumins ($p < 0.05$, $p < 0.01$), a decrease in urea after feeding, and an increase in the albumin to globulin ratio. In the HYB2 animals, there was a decrease in the urea blood levels, a slight increase in albumins, and the albumin-globulin ratio was higher than that in the Romanov sheep. The concentrations of creatinine (a phosphate residue donor for ADP, whose recovery to ATP increases

8. Rubailova N.G. *Otdalennaya gibrizatsiya domashnikh zhivotnykh* [Distant hybridization of farm animals]. Moscow, 1965 (in Russ.).
9. Giginishvili N.S. V knige: *Otdalennaya gibrizatsiya rastenii i zhivotnykh* [In: Distant hybridization in plants and animals]. Moscow, 1960 (in Russ.).
10. *Doklad komisii po geneticheskim resursam dlya proizvodstva prodovol'stviya i vedeniya sel'skogo khozyaistva (CGRFA-15/15/Report). FAO: Pyatnadtsataya ocherednaya sessiya* [Report of the Commission on Genetic Resources for Food and Agriculture. FAO: XV session]. Rome, 2015 (in Russ.).
11. Munn A.J., Dawson T.J., McLeod S.R., Dennis T., Maloney S.K. Energy, water and space use by free-living red kangaroos *Macropus rufus* and domestic sheep *Ovis aries* in an Australian rangeland. *Comparative Physiology*, 2013, 183(6): 843-858 (doi: 10.1007/s00360-013-0741-8).
12. Charismiadou M.A., Bizelis J.A., Rogdakis E. Metabolic changes during the perinatal period in dairy sheep in relation to level of nutrition and breed. I. Late pregnancy. *J. Anim. Physiol. Anim. Nutr.*, 2000, 84(3-4): 61-72 (doi: 10.1046/j.1439-0396.2000.00282.x).
13. Malau-Aduli A.E.O., Siebert B.D., Bottema C.D.K., Pitchford W.S. Heterosis, sex and breed differences in the fatty acid composition of muscle phospholipids in beef cattle. *J. Anim. Physiol. Anim. Nutr.*, 2000, 83(3): 113-120 (doi: 10.1046/j.1439-0396.2000.00255.x).
14. Bagirov V.A., Klenovitskiy P.M., Iolchiev B.S., Zinovieva N.A., Kalashnikov V.V., Shilo O.V., Soloshenko V.A., Nasibov Sh.N., Kononov V.P., Kolesnikov A.V. Cytogenetic characteristic of *Ovis ammon ammon*, *O. nivicola borealis* and their hybrids. *Agricultural Biology*, 2012, 6: 43-48 (in Engl., in Russ.) (doi: 10.15389/agrobiology.2012.6.43eng, doi: 10.15389/agrobiology.2012.6.43rus).
15. Arsen'ev D.D., Lobkov V.Yu. *Vestnik APK Verkhnevolzh'ya*, 2013, 3: 27-32 (in Russ.).
16. Danilkin A.A. *Mlekopitayushchie Rossii i sopredel'nykh regionov. Polorogie (Bovidae)* [Mammals of Russia and adjacent regions. Bovidae]. Moscow, 2005 (in Russ.).
17. Meza-Herrera C.A., Serradilla J.M., Mucoz-Mejias M.E., Baena-Manzano F., Menendez-Buxadera A. Effect of breed and some environmental factors on body weights till weaning and litter size in five goat breeds in Mexico. *Small Ruminant Res.*, 2014, 121(2-3): 215-219 (doi: 10.1016/j.smallrumres.2014.07.006).
18. Lourenço A.L., Dias-da-Silva A., Santos A.S., Rodrigues M.A.M., Cone J.W., Ferreira L.M.M. Comparative digestibility of low-quality grass hay by two breeds of cattle differing in mature live weight. *J. Anim. Physiol. Anim. Nutr.*, 2013, 98(3): 453-457 (doi: 10.1111/jpn.12090).
19. Zishiri O.T., Cloete S.W.P., Olivier J.J., Dzama K. Genetic parameters for growth, reproduction and fitness traits in the South African Dorper sheep breed. *Small Ruminant Res.*, 2013, 112(1-3): 39-48 (doi: 10.1016/j.smallrumres.2013.01.004).
20. Jetana T., Tasripoo K., Vongpipatana C., Kitsamra S., Sophon S. The comparative study digestion and metabolism of nitrogen and purine derivatives in male, Thai, Swamp buffalo and Thai, Brahman cattle. *Anim. Sci. J.*, 2009, 80(2): 130-139 (doi: 10.1111/j.1740-0929.2008.00618.x).
21. Sales J., Jančík F., Homolka P. Quantifying differences in total tract nutrient digestibilities between goats and sheep. *J. Anim. Physiol. Anim. Nutr.*, 2007, 96(4): 660-670 (doi: 10.1111/j.1439-0396.2011.01194.x).
22. Clauss M., Hofmann R.R., Streich W.J., Fickel J., Hummel J. Convergence in the macroscopic anatomy of the reticulum in wild ruminant species of different feeding types and a new resulting hypothesis on reticular function. *J. Zool.*, 2010, 281(1): 26-38 (doi: 10.1111/j.1469-7998.2009.00675.x).
23. Henderson G., Cox F., Ganesh S., Jonker A., Young W., Janssen P.H. Rumen microbial community composition varies with diet and host, but a core microbiome is found across a wide geographical range. *Scientific Reports*, 2015, 5, Article number: 14567 (doi: 10.1038/srep14567).
24. Lourenço A.L., Cone J.W., Fontes P., Dias-da-Silva A.A. Effects of ambient temperature and soybean meal supplementation on intake and digestion of two sheep breeds differing in mature size. *J. Anim. Physiol. Anim. Nutr.*, 2010, 94(5): 571-583 (doi: 10.1111/j.1439-0396.2009.00942.x).
25. Karasov W.H., Douglas A.E. Comparative digestive physiology. *Compr. Physiol.*, 2013, 3: 741-783 (doi: 10.1002/cphy.c110054).
26. Clauss M., Hummel J. The digestive performance of mammalian herbivores: why big may not be that much better. *Mammal Rev.*, 2005, 35: 174-187 (doi: 10.1111/j.1365-2907.2005.00062.x).
27. Aikman P.C., Reynolds C.K., Beever D.E. Diet digestibility, rate of passage, and eating and rumination behavior of jersey and Holstein cows. *J. Dairy Sci.*, 2008, 91: 1103-1114 (doi: 10.3168/jds.2007-0724).
28. Rihawi S., Iiguez L., Knaus W.F., Zaklouta M., Wurzing M., Soelkner J., Larbi A., Bomfim M.A.D. Fattening performance of lambs of different Awassi

- genotypes, fed under cost-reducing diets and contrasting housing conditions. *Small Ruminant Res.*, 2010, 94(1-3): 38-44 (doi: 10.1016/j.smallrumres.2010.06.007).
29. Özcan M., Demirel G., Yakan A., Ekiz B., Tölü C., Sav T. Genotype, production system and sex effects on fatty acid composition of meat from goat kids. *Anim. Sci. J.*, 2015, 86(2): 200-206 (doi: 10.1111/asj.12273).
 30. Kharitonov E.L. *Problemy biologii produktivnykh zhivotnykh*, 2008, 4: 42-71 (in Russ.).
 31. *Normy i ratsiony kormleniya sel'skokhozyaistvennykh zhivotnykh: Spravochnoe posobie* /Pod redaktsiei A.P. Kalashnikova, V.I. Fisina, V.V. Shcheglova, N.I. Kleimenova [Feed norms and rations for farm animals: handbook. A.P. Kalashnikov, V.I. Fisina, V.V. Shcheglov, N.I. Kleimenov (eds.)]. Moscow, 2003 (in Russ.).
 32. Ovsyannikov A.I. *Osnovy opytnogo dela v zhivotnovodstve* [Basics of experimental work in animal husbandry]. Moscow, 1976 (in Russ.).
 33. *Izuchenie pishchevareniya u zhvachnykh: Metodicheskie rekomendatsii* /Pod redaktsiei N.V. Kurilova [A study of digestion in ruminants: Guidelines. N.V. Kurilov (ed.)]. Borovsk, 1987 (in Russ.).
 34. *Metody veterinarnoi klinicheskoi laboratornoi diagnostiki: Spravochnik* /Pod redaktsiei I.P. Kondrakhina [Methods of veterinary clinical laboratory diagnostics. I.P. Kondrakhin (ed.)]. Moscow, 2004 (in Russ.).
 35. Merkur'eva E.K. *Biometriya v selektsii i genetike sel'skokhozyaistvennykh zhivotnykh* [Biometry in breeding and genetics of farm animals]. Moscow, 1979 (in Russ.).
 36. Niwińska B. Digestion in ruminants. In: *Carbohydrates — comprehensive studies on glycobiology and glycotechnology*. Chuan-Fa Chang (ed.). InTech d.o.o., Croatia, 2016 (doi: 10.5772/51574).
 37. Elsdon S.R., Hitchcock M.W.S., Marshall R.A., Phillipson A.T. Volatile acid in the digesta of ruminants and other animals. *Experimental Biology*, 1946, 22: 191-202.
 38. Van Vuuren A.M., Hindle V.A., Klop A., Cone J.W. Effect of maize starch concentration in the diet on starch and cell wall digestion in the dairy cow. *J. Anim. Physiol. Anim. Nutr.*, 2010, 94: 319-329 (doi: 10.1111/j.1439-0396.2008.00911.x).
 39. Recavarren M.I., Milano G.D. The rate and pattern of urea infusion into the rumen of wethers alters nitrogen balance and plasma ammonia. *J. Anim. Physiol. Anim. Nutr.*, 2014, 98(6): 1047-1053 (doi: 10.1111/jpn.12168).
 40. Rius A.G., Kittelmann S., Macdonald K.A., Waghorn G.C., Janssen P.H., Sikkema E. Nitrogen metabolism and rumen microbial enumeration in lactating cows with divergent residual feed intake fed high-digestibility pasture. *J. Dairy Sci.*, 2012, 95: 5024-5034 (doi: 10.3168/jds.2012-5392).