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Metabolic disorders as a factor influencing morphological and productive parameters in Holstein cows

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Abstract. The aim of the study was to establish the relationship between polymorbid pathology, morphological changes in the liver, and the productivity of animals at different lactations. A complex of clinical, morphological, histological, and cytometric methods was applied. A comparative analysis was conducted between the control and experimental groups of cows in their first, second, and third lactations. A total of 327 animals were examined, among which pathological conditions were detected in 60% of first-lactation cows, 53.57% of second-lactation cows, and 47.27% of third-lactation cows. For the morphological study, animals with combined metabolic disorders were selected, namely ketosis in combination with endometritis, mastitis, or hypocalcaemia. It was found that the proportion of such combinations was 20.95%, 17.85%, and 14.54% in the first, second, and third lactations, respectively. The average daily milk yield in the experimental groups was lower than in the control groups, while body weight significantly ($p < 0.05$) decreased across all age groups. The experimental animals showed an increase in both absolute and relative liver mass ($p < 0.001$), indicating functional hypertrophy of the organ. Histological examination revealed disruption of lobular architecture, diffuse vacuolisation of hepatocytes, areas of necrosis, infiltration of portal tracts, and the development of periportal fibrosis. In cows with a combination of ketosis and mastitis, signs of chronic hepatitis were observed, whereas in those with ketosis and hypocalcaemia, hepatosis with macrovesicular steatosis predominated. Cytometric analysis demonstrated a significant increase in the volume of hepatocytes and their nuclei ($p < 0.05$; $p < 0.01$) along with a decrease in the nuclear-to-cytoplasmic ratio, confirming the development of fatty degeneration. The degree of morphological alterations intensified with age and the duration of the lactation period. The practical value of the study lay in establishing morphological and cytometric criteria of liver lesions under polymorbid conditions, which could be applied to diagnose the level of metabolic load, predict disease progression, and develop preventive measures in animal husbandry

Keywords: lactation; ketosis-endometritis; ketosis-mastitis; ketosis-hypocalcemia; liver; morphology

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INTRODUCTION

Modern animal husbandry is undergoing a stage of profound transformation caused by both global economic changes and the consequences of military actions that have significantly affected the agricultural sector of Ukraine. The restoration of productive cattle herds and the improvement of their health are strategic objectives, as this sector forms the basis of food security by ensuring stable production of milk, meat, and other livestock products (Kotykova *et al*., 2024). Against this background, the issues of prevention and early diagnosis of metabolic disorders, particularly liver pathologies in high-yielding dairy cows, are of special importance, as they substantially affect productivity, reproductive ability, and overall health.

During the transition period, which encompasses the final weeks of gestation and the first weeks after calving, profound metabolic changes occur in the cow's body aimed at meeting the energy demands of lactation (Huralska *et al*., 2025a). As emphasised by M. Arshad and J. Santos (2024), this period is critical for maintaining physiological balance, since even a short-term energy deficit leads to the activation of pathological metabolic mechanisms. Fatty hepatosis is one of the leading causes of hepatic dysfunction and the related diseases and mortality in cattle. A. Vlizlo *et al.* (2024) reported that this disorder is most frequently registered in high-producing dairy cows during the postpartum period when energy demands reach their maximum. Its development is caused by an excessive influx of non-esterified fatty acids into the liver and intensified mobilisation of lipid reserves from body tissues. As a result, the hepatic parenchyma begins to accumulate triglycerides intensively, leading to a decrease in metabolic activity and a disturbance of energy metabolism (Zhang *et al*., 2023).

Predominantly, fatty hepatosis develops within the first four weeks after calving, when the organism experiences the maximum load associated with the onset of lactation. M. Tharwat *et al.* (2025) demonstrated that at this stage an excess of triglycerides, combined with hormonal fluctuations, creates favourable conditions for the development of steatosis and inflammatory processes in the hepatic tissue. When the rate of triglyceride synthesis exceeds their removal, these compounds, together with cholesterol esters, accumulate in hepatocytes. Under normal conditions, triglycerides are removed from the liver through the secretion of very-low-density lipoproteins or hydrolysis; however, this mechanism is impaired under metabolic disorders (Osada *et al*., 2024).

Alongside lipid imbalance, such animals exhibit increased formation of ketone bodies, resulting in endogenous intoxication, appetite suppression, reduced milk yield, and overall exhaustion. A particular danger is posed by the subclinical form of ketosis, when external signs of pathology are absent but productivity and reproductive capacity are significantly reduced. M. Bauer and W. Jagusiak (2022) noted that such latent forms of ketosis often remain unnoticed but cause the greatest economic damage to farms. The liver has a high compensatory potential; however, its reserves are limited. When glycogen, cofactors, and antioxidant systems are depleted, a state of decompensation develops, deepening structural and functional disorders. O. Olishevskyi and S. Huralska (2025) indicated that the combination of metabolic, inflammatory, and degenerative processes forms a complex polymorbid syndrome that leads to significant morphofunctional changes in the liver – from fatty degeneration and cytoplasmic vacuolisation to necrosis, fibrosis, and architectural disorganisation. The severity of these changes directly depends on the combination of diseases and the lactation period.

Thus, metabolic disturbances during the transition period in dairy cows, particularly the development of fatty hepatosis, represent one of the most serious challenges of modern dairy farming. Excessive lipid accumulation in the liver, energy metabolism disruption, and ketosis formation lead to reduced productivity, impaired reproductive function, and the development of polymorbid conditions. The aim of the study was to investigate the effect of polymorbid pathology of various combinations on the morphological and functional state of the liver in cows of different lactations, to determine the nature of structural alterations, and to establish their relationship with the level of animal productivity.

LITERATURE REVIEW

Fatty liver degeneration (hepatic lipidosis) is one of the most common metabolic disorders in dairy cattle, leading to substantial economic losses due to reduced milk yield, impaired reproductive performance, and increased culling rates (Melendez & Pinedo, 2024). Researchers have noted that both the incidence and severity of this disorder have increased in recent years, which may be a consequence of intensive selection for high productivity. Such genetic selection is accompanied by the emergence of pleiotropic genes associated with a higher predisposition to obesity, ketosis, and other metabolic complications. Although the high productivity of modern cows ensures considerable milk yields, it simultaneously reduces the organism's adaptive reserves and resistance to metabolic stress.

T. Swartz *et al.* (2021) and C. Zhang *et al.* (2024) emphasised that fatty liver degeneration is not merely a consequence of excessive lipid loading but rather a complex pathogenetic process linked to disturbances in energy metabolism, oxidative stress, and inflammatory responses. An excess of triglycerides in hepatocytes causes disruption of intracellular organelles, particularly mitochondria, thereby diminishing the liver's detoxification capacity and its ability to synthesise essential metabolites. This state leads to profound systemic dysfunctions, including impaired immune responses and increased susceptibility to infections. At the same time,

D. Giannuzzi *et al.* (2021) drew attention to the difficulties of early diagnosis of this disorder. Liver biopsy remains the gold standard; however, due to its invasiveness and technical complexity, it is unsuitable for large-scale screening. Therefore, the search for non-invasive biomarkers that would allow assessment of the degree of hepatic lipid infiltration at early stages remains an important direction in contemporary research.

Studies by Z. Cheng *et al.* (2023) revealed that impairment of hepatic function can markedly shorten the lifespan of dairy cows. Although under favourable conditions these animals are capable of living for more than 20 years, in modern high-yielding herds the average productive lifespan is only about three years after the first calving. In primiparous cows, inflammatory alterations in the liver were already detected at the beginning of the first lactation, later progressing to fibrosis. The authors concluded that each subsequent lactation accelerates the "ageing" process of hepatic tissue, aggravating metabolic and immune dysfunctions and thereby increasing the risk of premature culling. According to D. Giannuzzi *et al.* (2021), hepatic lipidosis is closely associated with ketosis, which is a common metabolic disorder in cows during the transition period. Both conditions develop as a result of a negative energy balance, when the energy required for lactation exceeds nutrient intake. Early detection of these disorders is a key factor in reducing their impact on herd productivity and improving profitability.

C. Zhang *et al.* (2023) further clarified that fatty liver degeneration is accompanied not only by triglyceride accumulation but also by structural tissue alterations, including fibrosis. This process results from excessive synthesis of extracellular matrix components in response to hepatocellular damage, disrupting lobular architecture and reducing the liver's synthetic and metabolic functions. Despite numerous studies, the pathogenesis of fibrosis in fatty liver degeneration remains insufficiently elucidated, opening new perspectives for further morphological and biochemical research. The study of the morphofunctional state of the liver in Holstein cows under metabolic and chronic disorders is particularly relevant, as this organ plays a central role in maintaining energy, protein, and lipid metabolism. Evaluation of body weight dynamics, hepatic structure, and function enables timely diagnosis of early stages of metabolic imbalance, development of preventive strategies, and enhancement of recovery efficiency in high-producing cows during the postpartum period.

MATERIALS AND METHODS

The study was conducted during 2022-2025 at PJSC PC "Podillia" (Dzyhivka village, Mohyliv-Podilskyi district, Vinnytsia region). The research had a comprehensive production-experimental design and was performed in accordance with the Law of Ukraine No. 3447-IV (2006), the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (1986), and the provisions of the Universal Declaration on Animal Welfare (2007). Ethical review of the study protocol was carried out following the recommendations of S. Huralska *et al.* (2025b).

The research was conducted on Holstein cows aged 3-7 years at different stages of lactation. The total sample included 327 animals, of which 105 were in the first lactation, 112 in the second, and 110 in the third. All cows were maintained under identical housing conditions, received balanced diets, and followed a standard milking routine in an "electronic herringbone" parlour system. For comparative analysis, the animals were divided into three control groups (clinically healthy) and three experimental groups (diagnosed with polymorbid pathologies), each corresponding to a specific lactation. The experimental groups included cows with ketosis combined with one of three concurrent disorders – endometritis, mastitis, or hypocalcaemia. Inclusion criteria comprised the presence of clinical signs of metabolic disorders confirmed by laboratory indicators and the absence of infectious or traumatic lesions. Exclusion criteria included cachexia, non-metabolic systemic inflammation, chronic hepatopathies, or postoperative changes.

Clinical examinations were performed using conventional veterinary diagnostic methods. Ketosis was diagnosed with the Ketotest® (KetoLact, Germany) rapid test and confirmed by laboratory determination of β-hydroxybutyrate in blood plasma (threshold >1.2 mmol/L). Endometritis was identified through clinical examination, vaginal inspection, and cytological evaluation of discharges. Mastitis was diagnosed using the *California Mastitis Test (CMT)* and somatic cell count in milk. Hypocalcaemia was detected photometrically by measuring total serum calcium (<2.0 mmol/L). Additionally, in the experimental animals, total protein, glucose, triglycerides, and alanine aminotransferase (ALT) activity were determined as indicators of hepatic functional status.

Morphological analysis of the liver was performed on samples collected from animals subjected to forced slaughter. Tissue specimens were fixed in 10% neutral formalin, dehydrated through graded alcohols, and embedded in paraffin. Sections of 5-7 μm thickness were prepared using a Leica RM2235 microtome. Staining was performed with haematoxylin and eosin to assess general architecture, Van Gieson's method to identify connective tissue elements, and Sudan III to visualise lipid inclusions. Microscopic examination was carried out using a Carl Zeiss Primo Star light microscope at ×400 and ×1000 magnifications. Morphological assessment included evaluation of lobular architecture, hepatocyte vacuolisation, necrotic changes, portal infiltration, connective tissue proliferation, and fibrosis development. Cytometric measurements were conducted using the Image Scope digital morphometric system (Aperio Technologies, USA). For each specimen, no fewer than 100 hepatocytes were analysed across 10

randomly selected fields of view. The following parameters were determined:

- mean hepatocyte volume (V_x, μm^3);
- mean nuclear volume (V_n, μm^3);
- nuclear-to-cytoplasmic ratio ($NCR = V_n/V_x$).

These indices were used for quantitative assessment of hepatocellular hypertrophy, lipid degeneration, and tissue disorganisation. Live body weight was measured individually before morning milking using Axis BCA-1500 electronic scales. Average daily milk yield was calculated from data of the automated Milk Master control system (GEA Farm Technologies, Germany) over 10 consecutive days during the stable lactation period. The analysed parameters included mean body weight, absolute and relative liver mass, milk yield, and body condition score (BCS) on a five-point scale. Data processing was carried out using Statistica 6.0 software (StatSoft Inc., USA). For each parameter, the mean (M), standard error (m), and significance level (p) were calculated using Student's t-test. Differences between groups were considered statistically significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$. Graphical visualisation was performed in Microsoft Excel 2021.

RESULTS AND DISCUSSION

In the examined cows, 60% of pathologies were recorded among 105 animals of the first lactation, 53.57% among 112 animals of the second lactation, and 47.27% among 110 animals of the third lactation. For the experiment, animals with polymorbid pathology were selected, namely the following combinations: ketosis–endometritis, ketosis–mastitis, and ketosis – hypocalcaemia. In cows of the first lactation, these pathologies accounted for 20.95%, in the second – 17.85%, and in the third – 14.54%. The average daily milk yield in the experimental group was 43.26 ± 2.02 kg ($p < 0.05$), 50.06 ± 1.51 kg, and 49.07 ± 2.14 kg, respectively. In the control group, the yield was 48.07 ± 1.56 kg, 51.40 ± 1.41 kg, and 50.27 ± 2.12 kg, respectively (Fig. 1).

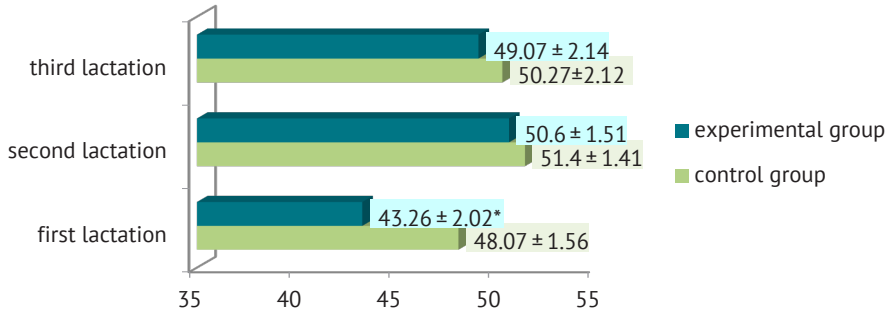

***Figure 1**. Average daily milk yield in experimental groups of animals, kg*
***Note:** p < 0.05 compared with control*
***Source:** developed by the authors*

The average body weight in the control group during the first lactation was 567.83 ± 5.67 kg, while in the experimental group of the same age this indicator was significantly lower ($p < 0.05$) and amounted to 533.66 ± 5.95 kg. A similar pattern was observed during the second and third lactations (Table 1).

***Table 1** Body weight indices of cows with polymorbid pathology (M ± m)*

Animal groups	Body weight, kg		
	first lactation	second lactation	third lactation
Control	567.83 ± 5.67	633.83 ± 7.47	661.67 ± 9.77
Experimental	533.66 ± 5.95*	556.33 ± 10.51*	570.66 ± 9.89*

***Note:** p < 0.05 compared with control*
***Source:** developed by the authors*

In cows, the liver is located on the right side of the abdominal cavity, adjoining the diaphragm. In clinically healthy animals, it has a reddish-brown colour and a soft consistency. In cows of the experimental group, the liver was enlarged, yellowish or yellow-brown in colour, and soft in texture. The absolute liver mass in the control group of cows during the first, second, and third lactations primarily depended on the animals' body weight indices. In cows of the experimental groups at different lactations, a significant ($p < 0.001$) increase in the absolute mass of the organ was observed compared with the control, whereas the body weight indices, as previously noted, were significantly ($p < 0.05$) lower relative to the control (Fig. 2).

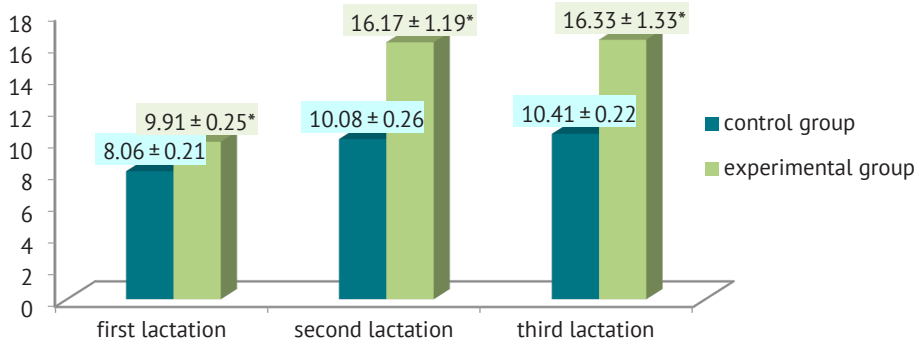

***Figure 2**. Absolute liver mass of cows with polymorbid pathology, kg*
***Note:** p < 0.05 compared with control*
***Source:** developed by the authors*

With high statistical significance (p < 0.001), the relative liver mass values predominated in the experimental groups across all lactations. Thus, in cows of the control group during the first lactation, this indicator was 1.42 ± 0.04, whereas in the experimental group it was 1.86 ± 0.06 (p < 0.001). The highest value of relative liver mass was recorded in experimental cows during the second lactation, amounting to 2.91 ± 0.22 (p < 0.001), which was 1.83 times higher compared with the corresponding control group (Fig. 3).

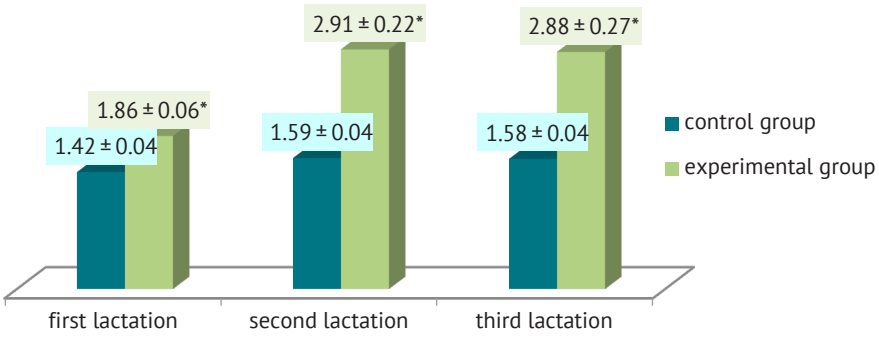

***Figure 3**. Relative liver mass of cows with polymorbid pathology*
***Note:** p < 0.05 compared with control*
***Source:** developed by the authors*

Histological examination of the liver in cows from the control groups revealed normal histoarchitectonics. The parenchyma of the organ consisted of polygonal lobules, with connective tissue septa between them being poorly developed. The lobules were formed by hepatic plates composed of hepatocytes, which perform most of the metabolic functions of the liver. At the corners of the hepatic lobules (between three adjacent lobules), triads consisting of a vein, an artery, and a bile duct were observed. It was established that in cows of the first lactation, the most frequent combination was ketosis with endometritis. Histological examination of the liver revealed moderate diffuse vacuolisation of hepatocyte cytoplasm, areas of diffuse necrosis, and lymphocytic–macrophage infiltration of the portal tracts. Disorganisation of hepatic plates and disturbance of lobular architecture were also noted. In cases of ketosis combined with hypocalcaemia, the hepatic plate structure was preserved; however, pronounced vacuolisation of hepatocytes, widespread necrosis, and slight lymphocytic–macrophage infiltration were observed. Such alterations indicate significant functional overload and damage to the hepatic parenchyma. In the combination of ketosis and mastitis, pronounced diffuse vacuolisation of hepatocytes (signs of severe fatty degeneration), moderate diffuse necrosis, and accumulation of inflammatory cells were observed, indicating the development of focal chronic hepatitis.

In cows of the second lactation with ketosis combined with endometritis, enlargement and structural changes of the portal tracts, areas of fibrosis around central veins, accumulation of inflammatory cells, and dilation of bile ducts were detected. These changes indicated chronic inflammation with the development of periportal fibrosis. The combination of ketosis and hypocalcaemia in cows of the second lactation was accompanied by pronounced diffuse vacuolisation of hepatocyte cytoplasm (macrovesicular steatosis), active necrosis, slight diffuse lymphocytic–macrophage

infiltration with eosinophils, and proliferation of connective tissue around the portal tracts. The obtained results indicated a severe form of hepatosis with signs of chronic inflammation and initial fibrosis, reflecting pronounced metabolic stress. In cows of the third lactation, the most frequently registered combination was ketosis with mastitis. Microscopic examination revealed signs of hepatosis with elements of chronic inflammation and fibrosis, confirmed by the presence of lymphocytes, macrophages, and connective tissue proliferation. Cytometric examination showed that hepatocytes differed in size and in the volume of their cytoplasm and nuclei. Analysis of these parameters demonstrated a significant increase in the mean hepatocyte and nuclear volumes in animals of the experimental groups across all lactations (Figs. 4, 5).

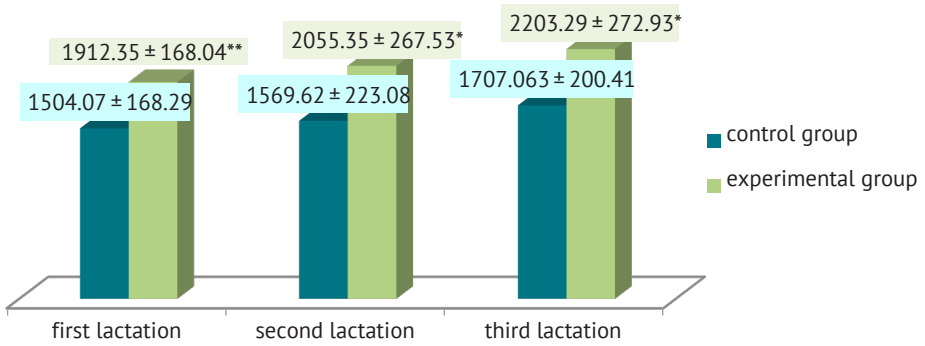

Figure 4. *Hepatocyte volume indices in control and experimental groups, μm³*
Note: *p < 0.05 compared with control*
Source: *developed by the authors*

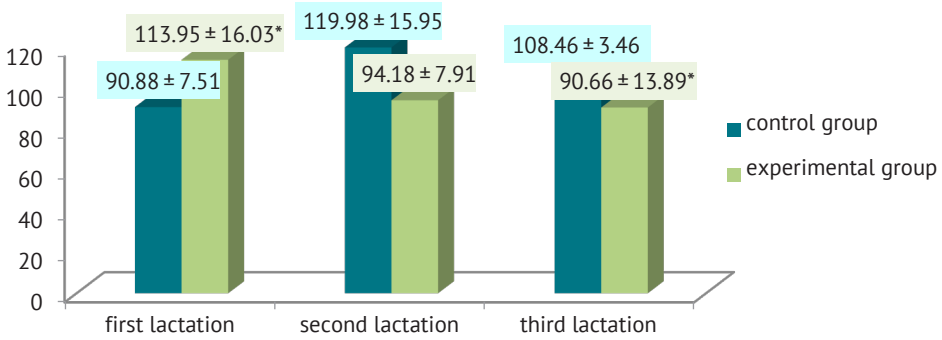

Figure 5. *Hepatocyte nuclear volume indices in control and experimental groups, μm³*
Note: p < 0.05 compared with control
Source: *developed by the authors*

In the experimental animals, as noted, hepatocellular damage was observed. In these cows, a significant increase in the volume of hepatocytes was recorded. According to cytometric data, in cows of the first lactation, the hepatocyte volume in the control group was 1504.07 ± 168.29 μm³, whereas in the experimental group it reached 1912.35 ± 168.04 μm³ ($p < 0.01$). In animals of the second and third lactations, this parameter also showed an increase ($p < 0.05$). A significant difference was also noted in the nuclear volume of hepatocytes between the control and experimental groups. Thus, in the first lactation, the experimental group exhibited a 1.25-fold ($p < 0.05$) increase compared with the control, whereas in the second and third lactations, the nuclear volume of hepatocytes was significantly lower – by 1.27 and 1.2 times, respectively. The nuclear-to-cytoplasmic ratio (NCR) of hepatocytes in all experimental groups with ketosis decreased compared with the control (Fig. 6). This indicates an increase in cytoplasmic volume relative to the nucleus, caused by the accumulation of lipid inclusions, vacuolisation, and the development of fatty degeneration.

In the experimental animals of the first lactation, a tendency towards a decrease in the nuclear-to-cytoplasmic ratio (NCR) was observed, while in the second and third lactations the decrease was significant ($p < 0.01$). In clinically healthy cows of the second lactation, the NCR value was 0.086 ± 0.014, whereas in the experimental animals it was 0.053 ± 0.008 ($p < 0.01$), being 1.62 times lower compared with the control. Summarising the results, it can be stated that polymorbid pathology in cows causes pronounced morphofunctional alterations in the liver, ranging from fatty degeneration and necrotic lesions of hepatocytes to the formation of fibrosis. The intensity of these pathological processes depends both on the combination of diseases and on the lactation period.

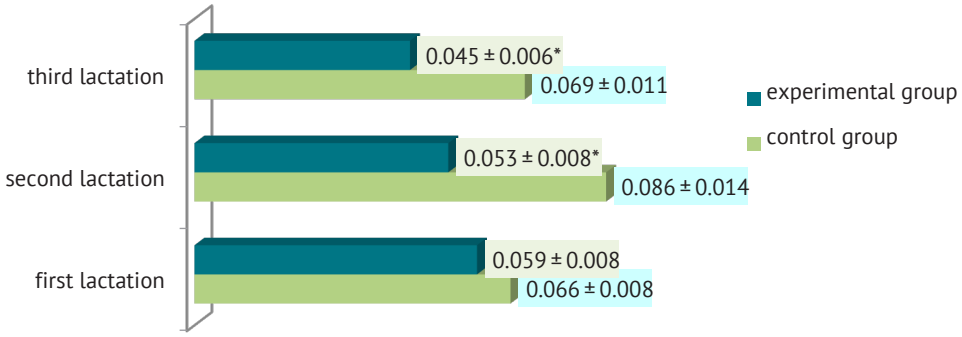

***Figure 6**. Nuclear-cytoplasmic ratio*

***Note:** p < 0.05 compared with control*
***Source:** developed by the authors*

The obtained results confirmed that the transition period in cows is a critical stage characterised by profound metabolic changes that significantly affect the condition of the liver. According to D. Kang *et al.* (2025), about 45-60% of dairy cows experience metabolic disorders during this period. U. Arshad and J. Santos (2024) reported that hepatic lipidosis develops in 40-50% of dairy cows in the first weeks of lactation. This stage is critical due to the substantial physiological and hormonal changes associated with the transition from rest to active lactation. In the present study, the frequency of detected pathologies was similar – 60% in cows of the first lactation, 53.57% in the second, and 47.27% in the third – which confirms the trends described in the literature. Hepatic pathology in dairy cows remains a relevant problem in modern animal husbandry since the liver plays a key role in maintaining energy balance during the transition period. According to K. Aksoy *et al.* (2025), the detection of hepatic lesions of varying degrees in 46% of examined samples indicates the widespread occurrence of both subclinical and clinical forms of hepatopathies among high-producing cows. The most common findings were inflammatory processes, whereas fibrosis and necrosis were rare, suggesting that most morphological changes are reversible if metabolic correction and diagnosis are performed in time. It should be noted that histopathological studies of the bovine liver still lack unified approaches for the quantitative evaluation of tissue damage, as most research is based on selective sample analysis, which can introduce bias in data interpretation (Hellen & Karpen, 2023). This highlights the need to standardise morphometric assessment methods for hepatocytes, fibrosis, and steatosis to ensure greater objectivity and comparability of results.

The obtained data correspond to findings from other studies confirming significant metabolic and hormonal changes during the period from late gestation to early lactation (McGuckin *et al.*, 2023). During this time, active lipid mobilisation from fat depots increases the metabolic load on the liver and may lead to steatosis, ketosis, and hepatodystrophy. According to Takahashi *et al.* (2021), lipid metabolism and lipoprotein profiles in cows vary depending on age and number of lactations, supporting the following results that demonstrated differences among cows of the first, second, and third lactations. Older cows showed a greater tendency for triglyceride accumulation in hepatocytes and a higher susceptibility to metabolic disorders. Histological findings by K. Theinert *et al.* (2022) are consistent with the following results, indicating that fat accumulation in the liver during the early postpartum period is a reversible process that gradually decreases toward the end of the lactation cycle. At the same time, lipidosis was found to correlate positively with the degree of cellular degeneration and inflammation. This study also confirmed that fibrosis occurred more frequently in older cows with a higher number of lactations, reflecting the cumulative effect of prolonged metabolic stress. These results have practical importance for monitoring hepatic condition in animals of different age groups.

Liver lesions in dairy cows are multifactorial and result from complex metabolic shifts occurring during the transition period. The detected morphological changes – from mild fatty infiltration to moderate hepatitis – confirm the reversibility of the pathological process and underline the importance of early diagnosis. The data obtained are consistent with the observations of L. Vogel *et al.* (2024), who considered postpartum lipid mobilisation in cows a natural model of metabolic stress, analogous to chronic liver diseases in humans. A decrease in the NCR in experimental animals compared with controls indicates the predominance of cytoplasmic alterations over nuclear ones, which may be caused by the accumulation of triacylglycerols and the development of fatty degeneration. These findings confirm the data of C. Zhang *et al.* (2024), who reported that hepatic lipidosis is not merely a consequence of excess fat accumulation but also a manifestation of systemic metabolic disorders accompanied by oxidative stress, inflammatory response, and damage to cellular organelles.

The link between the development of lipidosis and ketosis was also confirmed, as both conditions are driven by negative energy balance in the postpartum period. In animals with pronounced morphological changes in the liver, reduced synthetic function of the organ was

observed, which may lead to decreased productivity, impaired reproductive performance, and increased susceptibility to infections. These observations are in line with P. Melendez and P. Pinedo (2024), who reported significant economic losses associated with hepatoses in high-producing dairy cows. The detected cytological alterations can be regarded as morphological markers of disrupted adaptive mechanisms during the transition period. As noted by Z. Cheng *et al.* (2023), such animals exhibit accelerated "ageing" of hepatic tissue, reducing the productive lifespan of cows. The obtained results morphologically confirmed this mechanism, revealing signs of degeneration and initial fibrosis, as described by C. Zhang *et al.* (2023).

Thus, the conducted research demonstrated that fatty liver degeneration represents a typical morphological response to metabolic stress during the transition period, and its severity may serve as an indicator of the intensity of energy deficit. The results expand the understanding of the morphofunctional characteristics of the liver in dairy cows during the transition period, confirming the close relationship between inflammatory reactions and age-related physiological features of animals.

CONCLUSIONS

In cows with polymorbid pathology during the first, second, and third lactations, a significant ($p < 0.05$) decrease in live body weight was observed compared with the control groups – by 37.17 kg, 77.5 kg, and 91.01 kg, respectively. This indicates a disruption of energy metabolism and loss of structural reserves in the organism as a result of metabolic stress. The absolute and relative liver mass in the experimental groups was significantly higher ($p < 0.001$) compared with the control, indicating oedematous changes, infiltration, and accumulation of lipid inclusions in the hepatic parenchyma. The highest relative liver mass (2.91 ± 0.22) was recorded in cows of the second lactation, exceeding the control value by 1.83 times. Histological examination revealed, in animals of the experimental groups, disturbances in the architecture of hepatic lobules, diffuse vacuolisation of hepatocyte cytoplasm, focal necrosis, lymphocytic–macrophage infiltration, and development of fibrosis, indicating a combination of fatty degeneration with chronic hepatitis and periportal fibrosis. Cytometric analysis demonstrated a significant increase in hepatocyte and nuclear volumes in the experimental animals. In the control group of cows during the first lactation, the nuclear volume was 90.88 ± 7.51 μm^3, whereas in the experimental group it reached 113.95 ± 16.03 μm^3 ($p < 0.05$).

At the same time, a tendency toward a decrease in the nuclear-to-cytoplasmic ratio (NCR) was observed in the cows of the first lactation, and a significant reduction ($p < 0.01$) was recorded in the second and third lactations. In particular, during the second lactation, the NCR decreased from 0.086 ± 0.014 in the control to 0.053 ± 0.008 in the experimental group. This finding reflects the expansion of cytoplasm caused by lipid infiltration and the progression of fatty degeneration. A promising direction for further research is the determination of correlations between cytometric parameters of hepatocytes, biochemical markers of liver function, and clinical manifestations of ketosis, which will contribute to improving the diagnosis and prevention of hepatosis in dairy cows.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Метаболічні розлади як чинник змін морфологічних і продуктивних показників у корів голштинської породи

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Анотація. Метою роботи було встановити взаємозв'язок між поліморбідною патологією та морфологічними змінами печінки і продуктивністю тварин різних лактацій. У дослідженні застосовано комплекс клінічних, морфологічних, гістологічних і цитометричних методів. Проведено порівняльний аналіз показників у контрольних та дослідних групах корів першої, другої і третьої лактацій. Обстежено 327 тварин, серед яких у корів першої лактації патології виявлено у 60 %, другої – у 53,57 %, третьої – у 47,27 %. Для морфологічного досліду було відібрано тварин із поєднаними метаболічними захворюваннями, а саме кетозом у комбінації з ендометритом, маститом або гіпокальціємією. Встановлено, що питома частка таких комбінацій становила 20,95 %, 17,85 % і 14,54 % відповідно за першої, другої та третьої лактації. Середньодобові надої у дослідних групах були нижчими, ніж у контрольних, а маса тіла достовірно ($p < 0,05$) зменшувалась у всіх вікових групах. У дослідних тварин відмічали підвищення абсолютної і відносної маси печінки ($p < 0,001$), що свідчить про функціональну гіпертрофію органа. Гістологічно встановлено порушення архітектоніки часточок, дифузну вакуолізацію гепатоцитів, ділянки некрозу, інфільтрацію портальних трактів та розвиток перипортального фіброзу. У тварин із поєднанням кетозу та маститу виявляли ознаки хронічного гепатиту, тоді як при кетозі з гіпокальціємією переважали прояви гепатозу з макровезикулярним стеатозом. Цитометричний аналіз показав достовірне збільшення об'єму гепатоцитів і їх ядер у дослідних тварин ($p < 0,05$; $p < 0,01$) при одночасному зниженні ядерно-цитоплазматичного відношення, що підтверджує розвиток жирової дистрофії. Ступінь морфологічних порушень посилювався із віком і тривалістю лактаційного періоду. Практична цінність роботи полягає у встановленні морфологічних та цитометричних критеріїв ураження печінки при поліморбідних патологіях, що може бути використано для діагностики ступеня метаболічного навантаження, прогнозу перебігу захворювань і розробки профілактичних заходів у тваринництві

Ключові слова: лактація; кетоз-ендометрит; кетоз-мастит; кетоз-гіпокальціємія; печінка; морфологія