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BETWEEN TASTE AND WELFARE: METABOLIC PROFILE AND HISTOLOGICAL ASPECTS OF COMMON DUCKS (*Anas platyrhynchos*) FATTENED FOR CONSUMPTION

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Abstract

Forced fattening of ducks (Anas platyrhynchos) is a zootechnical practice used to obtain fatty liver (commercially called foie gras) and duck fat. Forced fattening raises important issues regarding animal welfare, being considered by many specialists to be an intensely stressful and invasive method. In this study, metabolic and histological changes were analyzed in a population of forced-fattened common ducks. Serum protein (TP, ALB, GG, BUN, CR), lipid (TL, TRY, CHOL), carbohydrate (BG), enzymatic (AST, ALT, ALP, GGT, TSB, DBI, LDH, ά-AMY, LIP, CK) and mineral (P, Mg) profiles were analyzed. The final results showed very significant differences between the initial and final values of the metabolic profiles, sometimes with the blood-brain barrier being overcome. Histological analyses also demonstrated pronounced, even degenerative, tissue structural changes.

Key words*: blood-brain barrier, ducks, forced fattening, stress, welfare.*

INTRODUCTION

Animal fattening represents an essential stage in meat production, with the primary objective of achieving rapid weight gain of the organism or, in some cases, of specific organs or tissues (liver, fat) (Michał Gornowicz et al., 2023; Kutay et al., 2024). Depending on the species (Marin et al., 2015; Bordei et al., 2020), fattening technologies differ in terms of digestive particularities (Marin et al., 2017), nutritional requirements, production systems, and performance parameters (Rehman & Zulfiqar, 2024; Gado et al., 2025). Optimizing the fattening process requires the correlation of genetics (Kremez et al., 2025; Răducuță et al., 2025), nutrition (Ungureanu et al., 2024), housing conditions, and sanitary-veterinary management in order to obtain high average daily gains and a low feed conversion ratio (Custură et al., 2021; Tudorache et al., 2021). Intensive fattening leads to high productivity but involves substantial feed costs. Extensive systems, sometimes traditional ones, are more environmentally sustainable (Mihai et al., 2022), but are less economically efficient (Syrůček et al., 2017). Animal fattening is not merely a technological process aimed at increasing body mass, but also an expression of the interaction between humans, the environment, and animals, reflecting the level of agricultural development and adaptation to local conditions (Adamczyk, 2018; Nica & Vidu, 2023).

Force-feeding is a procedure whereby animals are fed beyond their natural nutritional requirements, either to accelerate growth or to obtain certain culinary products (Skippon, 2013; Mohammed et al., 2014; Huber, 2024). Animal welfare organizations and some public health authorities consider force-feeding to be one of the most severe forms of suffering imposed on animals and reject gastronomic justifications

which, in their view, undermine animal welfare (Nollkaemper, 2023). In the European Union, which has some of the most advanced legislative standards concerning animal welfare, there are directives stipulating that animals must be fed in accordance with their physiological needs and must not be subjected to procedures that cause unnecessary suffering or injury (including psychological trauma) (Guémené & Guy, 2004; Nicolaisen et al., 2023). These aspects also derive from the level of education of the population in the member states (Ilovan et al., 2019), as well as from cultural-historical and socio-economic factors (Gligor et al., 2026). Nevertheless, there are several EU member states - such as France, Hungary, Bulgaria, and Spain -where force-feeding of birds and mammals is still practiced, despite public opposition and the recommendations of animal welfare institutions (Temple et al., 2012; Toth, 2012; Rochlitz & Broom, 2017). Other member states prohibit, or at least restrict the sale of animal products obtained through force-feeding. The most well-known form of force-feeding is the gavage of ducks and geese (Molnár et al., 2006; Wen et al., 2016), although similar practices are also encountered in other poultry species, such as turkeys (Vlad et al., 2025). Gavage results in the production of fatty liver (foie gras), defined under the legislation of France and the European Union as the liver of a duck or goose fattened through force-feeding.

The traditional fattening of palmipeds for the production of fatty liver represents one of the oldest agricultural practices in which biology, culinary tradition, and social history visibly intersect (Duhart, 2011; Saber, 2022). Originating from the ancestral history of hunting, humans observed the behavior of wild ducks and geese during the autumn period when, prior to migration, they consumed larger quantities of food, accumulating fat in their bodies and particularly in the liver. These fat reserves provided the energy required by the birds during migration (Johnson et al., 2014). Based on these behavioral observations, and later following the domestication of birds (Sheta et al., 2025), force-feeding became an important step toward obtaining high-quality animal products. Over the centuries, such techniques have been encountered in communities across Central and Eastern Europe, with Jewish communities playing a particularly significant role in their development and dissemination (Kuropatnicki, 2017). Approximately 100-150 years ago, rural areas where ducks and geese were raised - and consequently fattened - were mainly household farms located within the Pannonian Plain region, including Hungary, Slovakia, and Transylvania. Nevertheless, from a historical perspective, duck domestication originated in Asia (Chen et al., 2021). Fattening was a seasonal activity, typically practiced before the winter holidays, when corn - an important source of starch - had already been harvested and stored in barns. The birds were generally kept in confined spaces, which limited their freedom of movement and consequently reduced energy expenditure. Feed was introduced manually into the oral cavity, and within two to three weeks the ducks became visibly heavier. The outcomes of this process consisted of fatty liver, lard, and meat intended for winter consumption. These products represented an important source of calories during long and harsh winters.

During that period, the traditional fattening technique was practiced on a small scale, primarily for household needs (Bercu et al., 2025). Subsequently, with the development of large livestock and poultry production complexes, fattening practices began to be applied on an industrial scale. These techniques are undoubtedly unpleasant for ducks and geese, with evident psycho-affective and pathological impacts (Tremolada et al., 2020). Nevertheless, the outcomes were considered important in terms of taste and the nutritional needs of human populations. Consequently, the evaluation of such practices raises an important question regarding the balance between gastronomic preferences and animal welfare. In this context, the present study evaluated the physiological and histological impact of duck fattening performed in a traditional system within a family household located in Transylvania, Romania.

MATERIALS AND METHODS

The ducks and drakes included in the investigation originated from a family farm located in Cluj County, Romania. They were traditionally fattened by the owners for

household consumption over a period of two weeks, using a diet consisting of corn kernels soaked in water for approximately 30 minutes. For administration and lubrication of the pharynx and esophagus, sunflower oil (10 mL) was added. No tubes or beak-opening devices were used for gavage. The ducks were immobilized under the breeder's left arm; the beak was opened manually with the left hand, while the feed was administered with the right palm in small, successive portions. During the gavage procedure, after the feed was introduced between the two valves of the beak, the esophagus was gently massaged first in an oro-aboral direction and subsequently in a cranio-caudal direction, in order to facilitate efficient swallowing of the feed. The daily quantity of feed administered represented approximately 5% of the ducks' body weight. Thus, for ducks with an average body weight of approximately 2.5 kg, the daily feed ration was 125 g, whereas for drakes with an average body weight of approximately 3 kg, the daily ration was 150 g. This amount was administered in two daily meals, in the morning and in the evening. Drinking water was provided *ad libitum*. The stocking density for the birds subjected to fattening was 0.50 m² per duck.

For the blood analyses, a total of 12 ducks and 4 drakes were included in the study. Blood samples were collected by puncture of the brachial artery at the beginning of the fattening period (day 0) and at the end of the fattening period (day 12).

The collected samples were transferred into vacutainer tubes containing a clot activator to accelerate blood coagulation and facilitate serum separation. Under refrigerated conditions (2-4°C), the samples were transported to the Hematology and Biochemistry Laboratory of the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca. Biochemical determinations were performed using a UV-VIS Screen Master Touch spectro-photometer. The wavelengths used for the biochemical analyses are presented in Table 1.

Table 1. Wavelengths (λ) and analytical methods used for the determination of biochemical constituents in the blood plasma of ducks

Blood parameter	λ (nm)	Usual method
TP - Total Protein	540-560 nm	Biuret
ALB - Albumin	628 nm	Bromocresol Green (BCG)
γ-GLOB - Gamma globulin	540-560 nm	electroforeză / calcul din TP-ALB
BUN - Blood Urea Nitrogen	340 nm	Urease-GLDH
Cr - Creatinin	492-520 nm	Jaffé
TL - Total Lipids	520-550 nm	sulfo-phospho-vanillin
TRY - Triglycerides	500-546 nm	GPO-PAP
CHOL - Cholesterol	500-520 nm	CHOD-PAP
BG - Blood Glucose	500-546 nm	GOD-POD
TC - Total Calcium	570-580 nm	Arsenazo III
P - Phosphorus	340 nm	UV phosphomolybdate
Mg - Magnesium	520-550 nm	Xylidyl blue
ASAT - Aspartate aminotransferase	340 nm	IFCC kinetic
ALAT- Alanine aminotransferase	340 nm	IFCC kinetic
ALP - Alkaline phosphatase	405 nm	p-nitrophenyl phosphate
GGT - Gamma-Glutamyl Transferase	405 nm	γ-glutamyl-p-nitroanilide
TB - Total bilirubin	540 nm	Jendrassik-Grof
DB - Direct bilirubin	540 nm	Jendrassik-Grof
LDH - Lactate dehydrogenase	340 nm	NADH kinetic
α-Amylase - Alpha amylase	405 nm	CNPG3
LIP - Lipase	405 nm	DGGR
CK - Creatine kinase	340 nm	IFCC kinetic

For the histological investigation, tissue samples (e.g., liver, breast muscle, and leg muscle) were collected and fixed in 10% buffered formalin for three days, followed by progressive dehydration in ethyl alcohol solutions of 70%, 96%, and absolute concentration, for one hour at each stage. Clarification was performed through three successive 1-hour baths of 1-butanol, after

which the samples were embedded in paraffin. Tissue sections of 5 µm thickness were obtained and subsequently stained using Goldner's trichrome method.

All statistical analyses were performed using GraphPad Prism (version 8.0.1; GraphPad Software Inc., San Diego, CA, USA). The collected data were first organized and inspected in order to identify potential errors or missing values prior to analysis. Descriptive statistics were calculated for all measured parameters and are presented as mean ± standard deviation (mean ± SD). To evaluate potential differences between sexes, the measured parameters from male and female individuals were compared using an independent-samples Student's t-test. This test was selected because it allows the comparison of mean values between two independent groups. The level of statistical significance (α) was set at 0.05 for all analyses. Differences were considered statistically significant when the calculated p-value was lower than the established significance threshold ($p < 0.05$). All statistical tests were two-tailed. The results of the statistical analyses were subsequently used to interpret possible sex-related differences in the studied parameters.

RESULTS AND DISCUSSIONS

Force-feeding in birds represents an experimental and economic practice used to investigate the metabolic, physiological, and biochemical adaptations of the organism to excessive energy intake. In the present study, blood changes were analyzed in two groups of birds, drakes (males) and ducks (females), by comparing parameters measured before and after the fattening period (MBF vs. MAF and FBF vs. FAF). The analyses focused on five metabolic profiles, protein, lipid, carbohydrate, mineral, and enzymatic, in order to identify the biological adaptations and metabolic stress associated with force-feeding.

In drakes, total protein (TP) showed a slight increase after fattening (2.78→2.97 g/dL; d=0.19±0.57), without statistical significance, while creatinine (Cr) decreased significantly (0.52→0.26 mg/dL; d=0.26± 0.08), suggesting a redistribution of muscle mass in favor of fat deposition. Albumin (ALB) and gamma globulins (γ-GLOB) showed minor, non-significant changes, indicating maintenance of the overall protein status, but with a slight decrease in components involved in immune function.

In females, protein-related changes were more pronounced and statistically significant. Albumin (ALB) increased considerably (0.99→1.43 g/dL; d=0.44±0.178), while gamma globulins (γ-GLOB) decreased (0.67→0.53 g/dL; d=0.14±0.069). Blood urea nitrogen (BUN) showed a marked decrease (57.67→22.72 mg/dL; d=34.95± 6.084), indicating a reduction in protein and carbohydrate catabolism (Massimino et al., 2020). Creatinine increased moderately, suggesting maintenance of muscle mass. Comparatively, females exhibited more pronounced and statistically significant protein-related changes, highlighting a stronger adaptation of protein metabolism to fattening, accompanied by a redistribution of plasma proteins (Table 2).

Thus, it can be observed that females exhibit more pronounced protein-related changes than drakes, with significant increases in albumin (ALB) and decreases in gamma globulins (γ-GLOB) and blood urea nitrogen (BUN), reflecting a more pronounced hepatic adaptation to excess energy intake.

In both drakes and ducks, force-feeding produced marked increases in plasma lipids (Davail et al., 2003; Gheorghe et al., 2022). In drakes, total lipids (TL) doubled (656.18 → 1348.03 mg/dL; d = 691.9 ± 88.32), and cholesterol (CHOL) increased significantly (183.2 → 372.83 mg/dL; d = 189.6 ± 34.53) (Table 3). In females, the increases were even more pronounced: total lipids (TL) rose markedly (725.08 → 1487 mg/dL; d = 761.9 ± 158.8), cholesterol (CHOL) also increased (276.03 → 404.53 mg/dL; d = 128.5 ± 32.37), and triglycerides (TRY) nearly doubled (286.56 → 586.61 mg/dL; d = 300.05 ± 50.74). These changes indicate rapid fat accumulation and an intensification of hepatic lipid metabolism (Lo et al., 2022), associated with increased adipose tissue mass and enhanced energy mobilization (Chartrin et al., 2006; Lungu & Moise, 2025).

Table 2. Mean values, differences, and statistical significance of the differences for metabolic constituents in ducks (females), before and after force-feeding

Metabolic profile	FBF	FAF	Mean of diff.	P value
Proteic profile				
TP (g/dL)	5.45±0.045	5.06±0.133	0.39±1.246	p=0.2946, ns
ALB (g/dL)	0.99±0.014	1.43±0.012	0.44±0.178	p<0.0001, ****
γ-GLOB (g/dL)	0.67±0.006	0.53±0.008	0.14±0.069	p<0.0001, ****
BUN (mg/dL)	57.67±0.64	22.72±0.513	34.95±6.084	p<0.0001, ****
Cr (mg/dL)	0.27±0.007	0.53±0.018	0.26±0.217	p=0.0014, **
Lipidic profile				
TL (mg/dL)	725.08±5.226	1487±12.969	761.9±158.8	p<0.0001, ****
TRY (mg/dL)	286.56±2.259	586.61±4.288	300.05±50.74	p<0.0001, ****
CHOL (mg/dL)	276.03±2.447	404.53±2.44	128.5±32.37	p<0.0001, ****
Carbohydrate profile				
BG (mg/dL)	211.72±1.533	335.16±5.836	123.44±64.24	p<0.0001, ****
Mineral profile				
TC (mg/dL)	10.99±0.058	8.43±0.055	2.56±0.686	p<0.0001, ****
P (mg/dL)	3.14±0.03	5.94±0.059	2.80±0.747	p<0.0001, ****
Mg (mg/dL)	2.12±0.021	2.48±0.028	0.36±0.291	p=0.0012, **
Enzyme profile				
ASAT (U/L)	77.92±0.281	40.17±0.243	37.75±4.207	p<0.0001, ****
ALAT (U/L)	121.42±0.461	164.78±1.277	43.36±15.05	p<0.0001, ****
ALP (U/L)	670.81±3.488	327.48±6.322	343.33±71.78	p<0.0001, ****
GGT (U/L)	18.47±0.098	79.63±0.366	61.16±4.277	p<0.0001, ****
TB (mg/dL)	0.96±0.009	1.14±0.015	0.18±0.191	p=0.0065, **
DB (mg/dL)	0.72±0.01	0.89±0.023	0.17±0.289	p=0.0711, ns
LDH (U/L)	375.13±4.17	1352.09±6.788	976.96±86.01	p<0.0001, ****
α – AMY (U/L)	5805.63±38.128	13799.5±42.165	7993.37±552.3	p<0.0001, ****
LIP (U/L)	39.84±0.345	171.62±2.513	131.78±24.0	p<0.0001, ****
CK (U/L)	2057.33±17.707	1631.27±6.238	426.06±202.8	p<0.0001, ****

FBF – females before fattening; FAF – females after fattening; TP – Total Protein; ALB – Albumin; γ-GLOB – Gamma Globulin; BUN – Blood Ureea Nitrogen; Cr – Creatinine; TL – Total Lipids; TRY – Triglycerides; CHOL – Cholesterol; BG – Blood Glucose; TC – Total Calcium; P – Phosphorus; Mg – Magnesium; ASAT - Aspartate aminotransferase; ALAT - Alanine aminotransferase; ALP - Alkaline phosphatase; GGT – Gamma-Glutamyl transferase; TB – Total bilirubin; DB – Direct bilirubin; LDH - Lactate dehydrogenase; α-amylase – Alpha-amylase; LIP – lipase; CK - Creatine kinase.

Table 3. Mean values, differences, and statistical significance of the differences for metabolic constituents in drakes (males), before and after force-feeding

Metabolic profile	MBF	MAF	Mean of diff.	p-value
Proteic profile				
TP (g/dL)	2.78 ± 0.021	2.97 ± 0.037	0.19 ± 0.57	p=0.5623, ns
ALB (g/dL)	1.28 ± 0.023	1.18±0.017	0.10 ± 0.25	p=0.4549, ns
γ-GLOB (g/dL)	0.2±0.005	0.17±0.004	0.03 ± 0.08	p=0.5117, ns
BUN (mg/dL)	13.65±0.186	15.8±0.08	2.15 ± 2.55	p=0.1907, ns
Cr (mg/dL)	0.52±0.009	0.26±0.005	0.26 ± 0.08	p=0.0075, **
Lipidic profile				
TL (mg/dL)	656.18±6.256	1348.03±11.492	691.9 ± 88.32	p=0.0006, ***
TRY (mg/dL)	255.33±3.707	355.68±4.395	100.4 ± 70.9	p=0.0062, ns
CHOL (mg/dL)	183.2±0.705	372.83±3.368	189.6 ± 34.53	p=0.0016, **
Carbohydrate profile				
BG (mg/dL)	237.13±4.28	289.38±2.591	52.25 ± 28.82	p=0.0361, *
Mineral profile				
TC (mg/dL)	10.79±0.05	8.96±0.025	1.83 ± 0.701	p=0.0136, *
P (mg/dL)	7.83±0.082	4.52±0.046	3.31 ± 0.414	p=0.0005, ***
Mg (mg/dL)	2.55±0.037	2.35±0.032	0.2 ± 0.654	p=0.584, ns
Enzyme profile				
ASAT (U/L)	24±0.339	28.75±0.24	4.75 ± 4.735	p=0.1385, ns
ALAT (U/L)	139.98±1.001	168.8±0.756	28.82 ± 15.54	p=0.0341, *
ALP (U/L)	221.23±2.466	382.98±1.833	161.75 ± 33.27	p=0.0023, **
GGT (U/L)	28.52±0.436	80.35±0.539	51.83 ± 8.674	p=0.0013, **
TB (mg/dL)	1.23±0.008	1.39±0.006	0.16 ± 0.131	p=0.0965, ns
DB (mg/dL)	1.1±0.014	1.08±0.01	0.02 ± 0.188	p=0.8684, ns
LDH (U/L)	408.88±4.449	1048.35±6.059	639.5 ± 46.23	p=0.0001, ***
α – AMY (U/L)	6189.25±23.041	14055.5±53.659	7866.25 ± 485.7	p<0.0001, ****
LIP (U/L)	42.3±0.508	388.35±3.523	346.05 ± 32.36	p=0.0002, ***
CK (U/L)	960.38±8.272	1217.28±13.781	256.9 ± 200.8	p=0.0833, ns

MBF – males before fattening; MAF – males after fattening; TP – Total Protein; ALB – Albumin; γ-GLOB – Gamma Globulin; BUN – Blood Ureea Nitrogen; Cr – Creatinine; TL – Total Lipids; TRY – Triglycerides; CHOL – Cholesterol; BG – Blood Glucose; TC – Total Calcium; P – Phosphorus; Mg – Magnesium; ASAT - Aspartate aminotransferase; ALAT - Alanine aminotransferase; ALP - Alkaline phosphatase; GGT - Gamma-Glutamyl transferase; TB – Total bilirubin; DB – Direct bilirubin; LDH - Lactate dehydrogenase; α-amylase - Alpha-amylase; LIP – lipase; CK - Creatine kinase.

Comparatively, lipid-related changes were more pronounced in females, with higher values of total lipids (TL) and triglycerides (TRY) and greater percentage increases than those observed in drakes (Atallah et al., 2024). This suggests a faster and more efficient metabolic adaptation of lipid metabolism in females, likely associated with sex-related hormonal differences.

Blood glucose increased significantly in both groups, reflecting the elevated energy intake. In drakes, blood glucose (BG) increased (237.13 → 289.38 mg/dL; d = 52.25 ± 28.82), while in females the increase was much more pronounced (211.72 → 335.16 mg/dL; d = 123.44 ± 64.24).

Thus, females exhibited more marked hyperglycemia, highlighting a stronger energetic adaptation for lipid synthesis and carbohydrate utilization (Sweazea, 2022).

Changes in mineral profiles showed a different pattern between the sexes. In drakes, calcium (TC) and especially phosphorus (P) decreased markedly (7.83 → 4.52 mg/dL; d = 3.31 ± 0.414), while magnesium (Mg) did not change significantly (2.55 → 2.35 mg/dL; d = 0.2 ± 0.654), indicating metabolic utilization associated with energy synthesis and hepatic adaptations. In females, calcium (TC) decreased (10.99 → 8.43 mg/dL; d = 2.56 ± 0.686), but phosphorus (P) increased significantly (3.14 → 5.94 mg/dL; d = 2.80 ± 0.747), and magnesium (Mg) showed a moderate increase (2.12 → 2.48 mg/dL; d = 0.36 ± 0.291). This pattern suggests a more complex mineral mobilization in females, associated with adaptations in energy and bone metabolism, possibly related to ATP synthesis and lipid storage. Therefore, females exhibited more complex and pronounced changes than drakes, with decreases in calcium (TC) and increases in phosphorus (P) and magnesium (Mg), indicating stronger metabolic and hormonal adaptations (Negm & Mohammed, 2023).

Enzymatic changes were pronounced in both sexes, although they followed different patterns. These alterations were primarily induced by force-feeding, although similar changes may also occur with advancing age in ducks (Hmangaihzuali et al., 2023). In drakes, very large post-fattening increases were observed for alpha-amylase (α-AMY) (6189.25 → 14055.5 U/L; d = 7866.25 ± 485.7), indicating intense pancreatic activity. Significant increases were also recorded for lactate dehydrogenase (LDH) (408.88 → 1048.35 U/L; d = 639.5 ± 46.23), gamma-glutamyl transferase (GGT) (28.52 → 80.35 U/L; d = 51.83 ± 8.674), alkaline phosphatase (ALP) (221.23 → 382.98 U/L; d = 161.75 ± 33.27), alanine aminotransferase (ALAT) (139.98 → 168.8 U/L; d = 28.82 ± 15.54), and lipase (LIP) (42.3 → 388.35 U/L; d = 346.05 ± 32.36). In contrast, the increases observed for aspartate aminotransferase (ASAT), direct bilirubin (DB), total bilirubin (TB), and creatine kinase (CK) were not statistically significant.

Dramatic increases in several enzymatic constituents were also observed in ducks, particularly in the case of alpha-amylase (α-AMY) (5805.63 → 13,799.5 U/L; d = 7,993.37 ± 552.3), alanine aminotransferase (ALAT) (121.42 → 164.78 U/L; d = 43.36 ± 15.05), gamma-glutamyl transferase (GGT) (18.47 → 79.63 U/L; d = 61.16 ± 4.277), lactate dehydrogenase (LDH) (375.13 → 1,352.09 U/L; d = 976.96 ± 86.01), and lipase (LIP) (39.84 → 171.62 U/L; d = 131.78 ± 24.0). Very significant differences were also observed in the opposite direction, with decreases after fattening for several enzymatic constituents in ducks: aspartate aminotransferase (ASAT) (77.92 → 40.17 U/L; d = 37.75 ± 4.207), alkaline phosphatase (ALP) (670.81 → 327.48 U/L; d = 343.33 ± 71.78), and creatine kinase (CK) (2057.33 → 1631.27 U/L; d = 426.06 ± 202.8). These findings suggest complex metabolic adaptations, involving intense hepatic and pancreatic redistribution, differentiated from the pattern observed in drakes by the decreases in ALP and ASAT.

Enzymatic–metabolic changes were pronounced in both sexes, with alpha-amylase (α-AMY) and lactate dehydrogenase (LDH) showing substantial increases. However, females exhibited a more complex redistribution between hepatic and bone-related enzymes, which may reflect hormonal and sex-related differences in metabolic adaptation.

The comparison of metabolic responses between female and male ducks highlights a markedly greater intensity of biochemical changes in females following force-feeding (Farhat & Chavez, 2000; Chia et al., 2022). Although both sexes exhibited increases in lipid parameters and

alterations in carbohydrate metabolism, the magnitude of metabolic reorganization was significantly more pronounced in females, suggesting a superior hepatic lipogenic capacity (Jerabek, 2018). In birds, the liver represents the primary site of fatty acid synthesis (Mancinelli et al., 2022), and the high carbohydrate intake derived from a corn-based diet promotes the conversion of glucose into triglycerides and other circulating lipids (Zaefarian et al., 2019; Cao et al., 2025). Females show a more intense activation of these processes, a phenomenon associated with physiological particularities of lipid metabolism influenced by estrogenic hormones, which stimulate lipid synthesis and transport (Yang et al., 2024). In contrast, males display smaller changes in serum proteins and nitrogen-related markers, suggesting a relative stability of protein metabolism and a more efficient metabolic adaptation to excess energy intake. Moreover, the hepatic enzymatic response is more pronounced in females, indicating greater hepatic metabolic activity and a higher sensitivity of the liver to nutritional overload. The increase in digestive and hepatic enzymes (Zeng et al., 2022) observed in both sexes reflects the adaptation of the digestive system to accelerated feed intake (Awde et al., 2013); however, its association with more extensive systemic metabolic changes in females suggests a metabolic redirection predominantly toward lipogenesis. Overall, these results indicate that females respond to force-feeding through a deeper metabolic reprogramming characterized by intensified hepatic lipid and carbohydrate metabolism, whereas males exhibit a more moderate and balanced metabolic adaptation.

Histologically, the liver lesions observed were represented by vacuolation of the hepatic parenchyma cells in the lobules. In both male and female ducks, the hepatocytes with lipidic inclusions were identified in all three zones of hepatic lobules, suggesting a diffuse hepatic lipidosis (Figures 1 and 2). Regarding the histological appearance of the affected hepatocytes, they had a multilocular appearance due to the presence of several uneven lipidic inclusions in the cytoplasm. The nucleus of these hepatocytes is usually eccentrically located but still with a spherical appearance and with a prominent central or paracentral nucleolus. As a consequence of a significant lipidic accumulation in hepatocytes, the cords of Remak were hypertrophied (Figure 2), a fact that induced the compression atrophy of the sinusoid capillaries (Figure 1). However, another aspect detected both in male and female ducks is the discrete fibrosis of the centrilobular venule (Figures 1 and 2). No inflammatory cells were identified in the specimens assessed.

The microscopic features detected in the muscles assessed were represented by the multifocal accumulation of lipids in the stromal connective tissue of the pectoral and leg muscle (Figures 3-6). The muscular lipomatosis was identified in both female and male ducks and induced multifocal hypertrophy of the perimysium, which is presenting large aggregates of monovacuolated or plurivacuolated adipocytes (Figures 3-6). In some microscopic areas, isolated or small groups of adipocytes were identified in between the myofibers, inducing the hypertrophy of the endomysium (Figures 4 and 6).

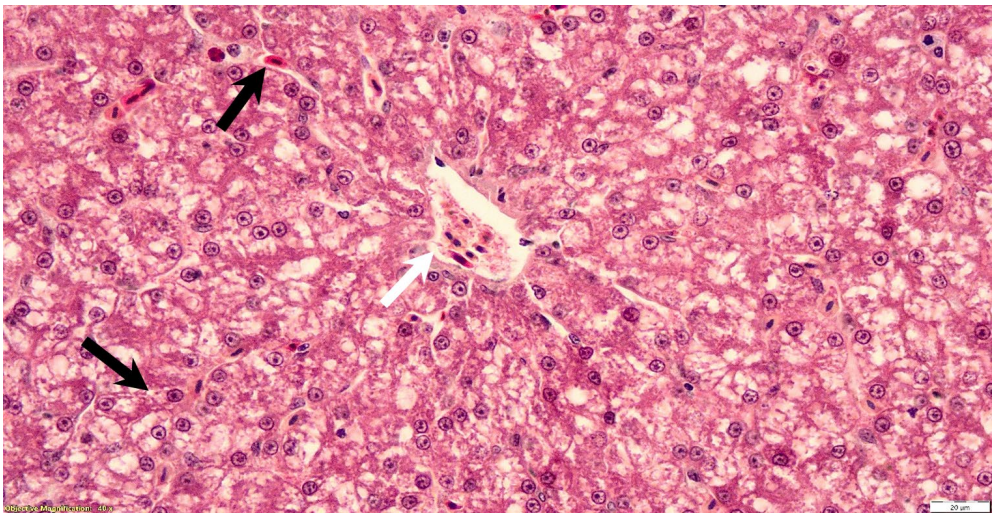

Figure 1. Diffuse hepatic lipidosis in a male duck: hypertrophied hepatocytes with a foamy aspect of the cytoplasm (arrowhead) due to accumulation of triglycerides and compression atrophy of the sinusoid capillaries (black arrow); discrete fibrosis of the centrilobular venule (blank arrow); GT stain (Original photo)

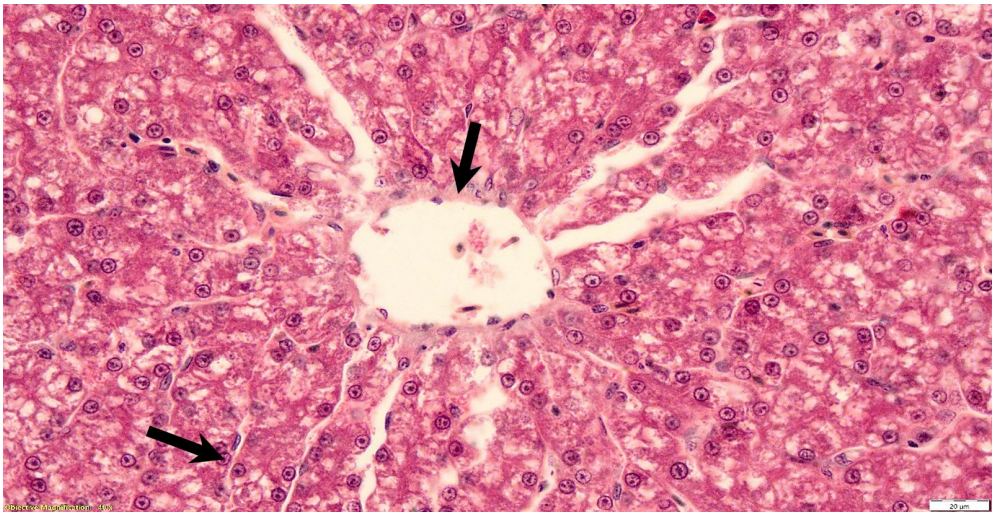

Figure 2. Diffuse hepatic lipidosis in a female duck: fibrosis of the centrilobular venule (black arrow) along with hypertrophy of the Remak's cords (arrowhead) due to accumulation of fatty material in the cytoplasm of hepatocytes; GT stain (Original photo)

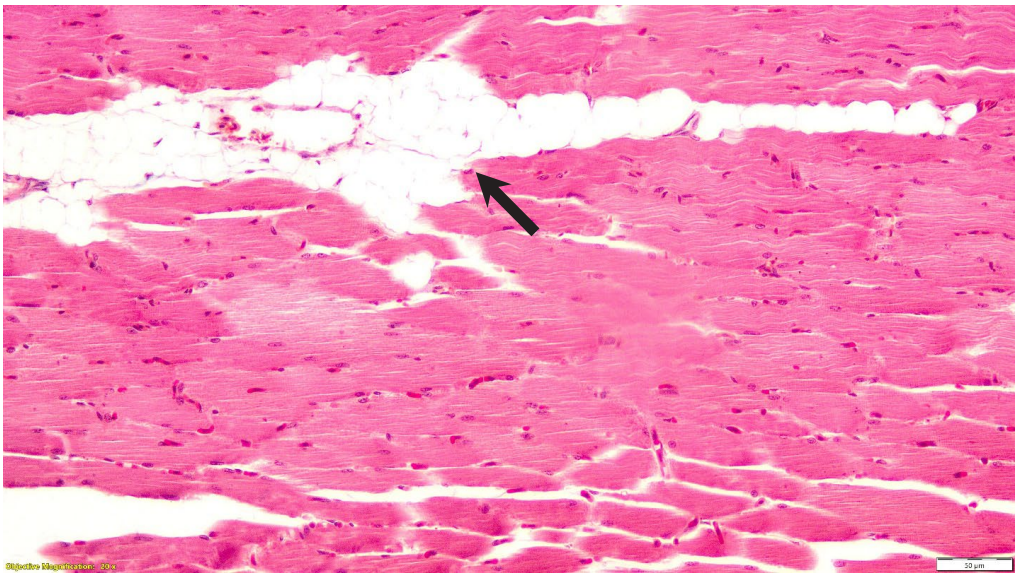

Figure 3. Muscular lipomatosis (pectoral muscle *Pectoralis major*, male duck): focal hypertrophy of the stromal connective tissue from the perimysium due to the presence of large aggregates of white adipocytes (arrow); GT stain (Original photo)

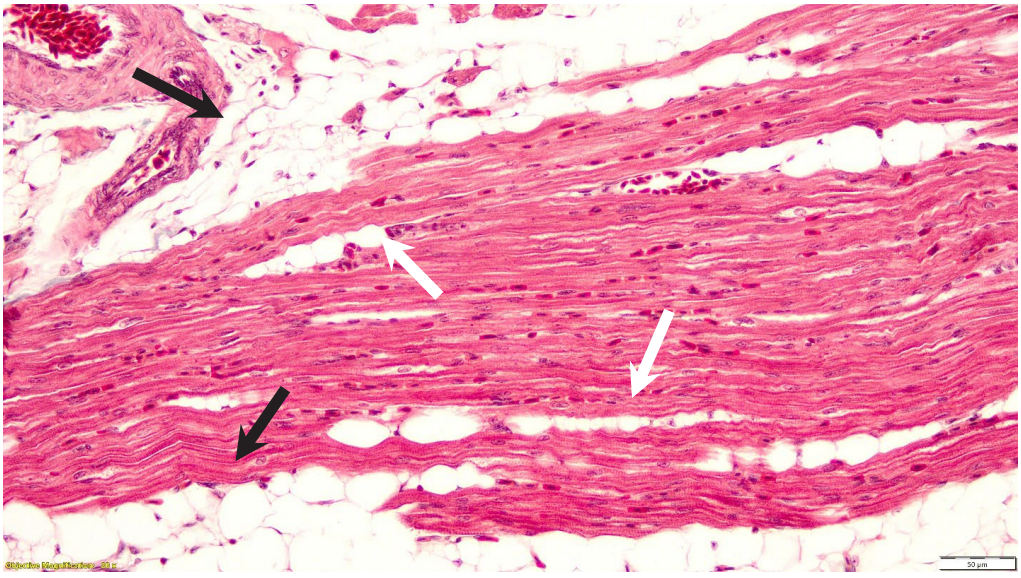

Figure 4. Muscular lipomatosis (pectoral muscle *Pectoralis major*, female duck): the presence of large groups of adipocytes in both perimysium (black arrows) and endomysium (blank arrows); GT stain (Original photo)

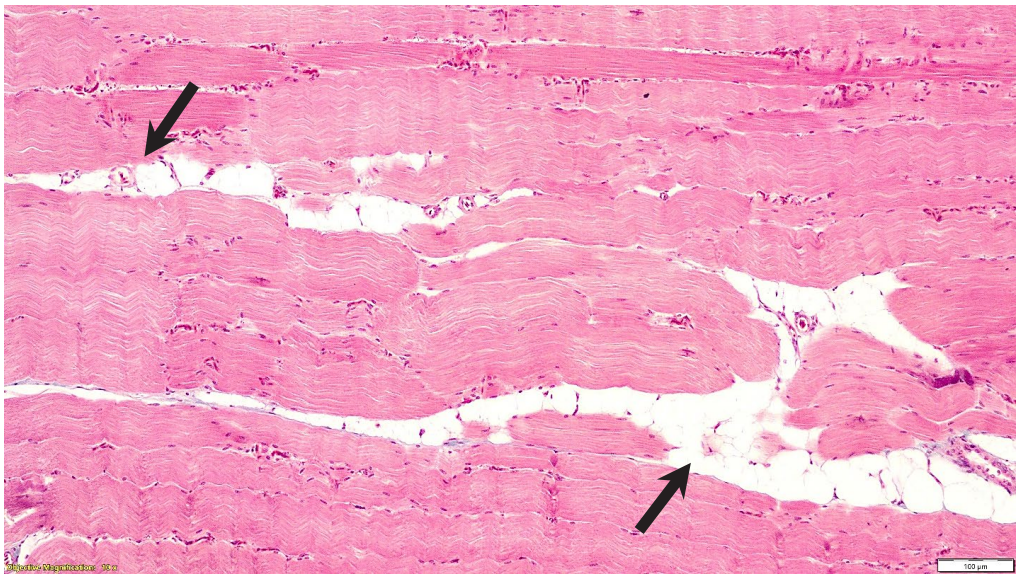

Figure 5. Muscular lipomatosis (leg muscle *Gluteus profundus*, male duck): groups of adipocytes in the perimysium (black arrows); GT stain (Original photo)

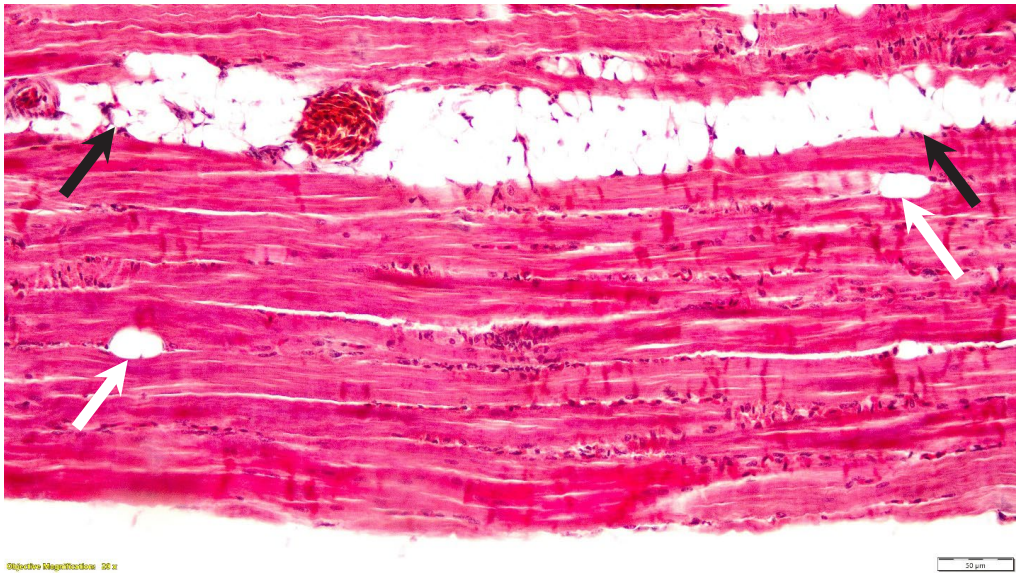

Figure 6. Muscular lipomatosis (leg muscle *Gluteus profundus*, female duck): large aggregates of adipocytes in perimysium (black arrows) and scattered adipocytes in between myofibers (blank arrows); GT stain (Original photo)

CONCLUSIONS

The metabolic study of ducks and drakes subjected to force-feeding highlights sex-related differences in physiological adaptation. Females exhibited pronounced changes in the protein compartment, with increases in albumin and decreases in globulins, suggesting an intense hepatic response and a redistribution of transport capacity and immune defense. These changes were accompanied by massive accumulations of lipids, triglycerides, and cholesterol, together

with marked increases in glucose, indicating a substantial metabolic transformation and significant energetic stress. Markers of hepatic and muscular enzymes signaled metabolic adaptations and evident micro-lesions at the tissue level, while the mineral balance remained actively regulated. In contrast, males displayed much more moderate protein-related changes: total proteins and albumin remained relatively stable, and urea and globulins suggested a balanced protein metabolism. Nevertheless, the lipid system also responded in males, with significant increases in total lipids and cholesterol, while hepatic and digestive enzymes indicated activation of energy metabolism and signs of moderate tissue stress. Glucose and mineral parameters showed less dramatic adjustments compared with females. Thus, females appear to be more vulnerable to metabolic imbalances and severe energetic stress, responding through marked hepatic and enzymatic adaptations, whereas males adopt a more conservative strategy, maintaining protein stability and regulating energy storage with a lower impact on overall metabolic balance. This difference highlights a clear sexual metabolic dimorphism, with females being more reactive to nutritional excess and males more resistant to protein-related disturbances, although both sexes exhibit adjustments in lipid metabolism and enzymatic activity. Ducks subjected to force-feeding showed clear signs of metabolic stress and blood biochemical imbalance, indicating a considerable level of physiological strain. Histological results revealed the presence of diffuse hepatic lipidosis in ducks, characterized by lipid accumulation within hepatocytes and structural alterations of the hepatic lobules, without associated inflammatory reaction. At the muscular level, multifocal lipomatosis was also observed, manifested by adipocyte accumulation within the stromal connective tissue, leading to hypertrophy of the perimysium and endomysium. These findings indicate significant lipid infiltration at both the hepatic and muscular levels. Despite these physiological effects, the practice continues to be employed for the production of high-quality traditional products, particularly fatty liver (foie gras), highlighting an ongoing compromise between animal welfare and gastronomic demand.

REFERENCES

Adamczyk, K. (2018). Dairy cattle welfare as a result of human-animal relationship – a review. *Annals of Animal Science*, *18*(3), 601-622.

Atallah, E., Trehiou, S., Alquier-Bacquie, V., Lasserre, F., Arroyo, J., Molette, C., & Remignon, H. (2024). Development of hepatic steatosis in male and female mule ducks after respective force-feeding programs. *Frontiers in Physiology*, *15*, 1392968.

Awde, S., Marty-Gasset, N., Wilkesman, J., & Rémignon, H. (2013). Proteolytic activity alterations resulting from force-feedingin Muscovy and Pekin ducks. *Poultry Science*, *92*(11), 2997-3002.

Bercu, A. G., Nicolae, C. G., Tăpăloagă, P. R., & Marin, M. (2025). Consumer demand for traditional food products: a qualitative and quantitative perspective. *Scientific Papers. Series D. Animal Science, LXVIII*(2), 668-675.

Bordei, I. Ș., Ianițchi, D., Marin, M. P., Maftei, M., Gavirș, T., Gheța, M., & Nicolae, C. G. (2020). Meat characteristics of wild pheasant versus farmed pheasant. *Scientific Papers. Series D. Animal Science*, *LXIII*(2), 383-388.

Cao, Z., Wang, L., Zhang, Y., Chang, G., & Chen, G. (2025). Hepatic fatty acid profile and gut microbiome responses of ducks induced by dietary n-6/n-3 polyunsaturated fatty acid ratio. *Poultry Science*, *104*(11), 105873.

Chartrin, P., Bernadet, M. D., Guy, G., Mourot, J., Hocquette, F., Rideau, N., Duclos, M. J., & Baéza E. (2006). Does overfeeding enhance genotype effects on liver ability for lipogenesis and lipid secretion in ducks? *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *145*(3), 390-396.

Chen, X., Shafer, D., Sifri, M., Lilburn, M., Karcher, D., Cherry, P., Wakenell, P., Fraley, S., Turk, M., & Fraley, G. S. (2021). Centennial Review: History and husbandry recommendations for raising Pekin ducks in research or commercial production. *Poultry Science*, *100*(8), 101241.

Chia, S. S., Adagi, J. M., Ate, M. E., & Uma, K. S. (2022). Comparative studies on blood serum profiles of liver enzymes, proteins, total bilirubin and liver organ morphometry of Muscovy ducks. *Black Sea Journal of Agriculture*, *5*(2), 167-171.

Custură, I., Tudorache, M., Gheorghe, A., Van, I., Marin, M. P., Bahaciu, G. V., Șuler, A. D., Marmandiu, A., Popescu-Micloșanu, E., Șonea, C. (2021). Breeding and production parameters obtained from the common duck, *Scientific Papers, Series D, Animal Science, 64*(1), 323-327.

Davail, S., Rideau, N., Guy, G., André, J. M., & Hoo-Paris, R. (2003). Pancreatic hormonal and metabolic responses in overfed ducks. *Hormone and Metabolic Research*, *35*(7), 439-443.

Duhart, F. (2011). The early phases of the foie gras industry in South-West France (C. 1780-1955): a contribution to the history of food innovation. *Revista de Humanidades*, *17*, 163-174.

Farhat, A., & Chavez, E. R. (2000). Comparative performance, blood chemistry, and carcass composition of two lines of Pekin ducks reared mixed or separated by sex. *Poultry Science*, *79*(4), 460-465.

Gado, H. M., Ahmed, D. A., Elghandour, M. M. M. Y., De Palo, P., D'Alessandro, A. G., & Salem, A. Z. M. (2025). Impact of increasing dietary energy on fattening steers growth performance, feed efficiency, and metabolic traits. *Tropical Animal Health and Production*, *57*, 345.

Gheorghe, A., Custură, I., Lefter, N., Idriceanu, L., Tudorache, M., Dumitru, M., & Hăbeanu, M. (2022). Assessment of plasma biochemistry and intestinal microflora in Transylvanian Naked Neck breed compared with commercial breeders, *Scientific Papers, Series D, Animal Science, 65*(1), 376-386.

Gligor, V., Creţan, R., Nicula, E. A., & Nicula, A. S. (2026). Assessing multifunctional mountain landscape in an Eastern European framework. *Geographical Research*, *64*, e70066.

Gornowicz, E., Dobek, A., Moliński, K., & Szwaczkowski, T. (2023). The quality of duck meat from the perspective of physical measurements and expert judgment. *Annals of Animal Science*, *23*(1), 265-273.

Guémené, D., Guy, G. (2004). The past, present and future of force-feeding and "foie gras" production. *World's Poultry Science Journal*, *60*, 211-222.

Hmangaihzuali, E. V. L., Sarma, K., Dutta, J., Talukdar, M., Rajchowa, J., & Malsawmsangi, A. B. (2023). Estimation of the changes in serum enzyme and metabolites of male Pati duck (*Anas platyrhynchos*) during post natal development. *The Pharma Innovation Journal*, *12*(5), 806-809.

Huber, K. (2024). Review: Welfare in farm animals from an animal-centred point of view. *Animal*, *18*(10), 101311.

Ilovan, O. R., Dulamă, M. E., Havadi-Nagy, K. E., Bojan, C. N., Horvát, C., Nițoaia, A., & Nicula, A. S. (2019). Environmental education and education for sustainable development in Romania. Teachers' perceptions and recommendations (II). *Romanian Review of Geographical Education*, *VIII*(2), 21-37.

Jerabek, M., Suchy, P., Strakova, E., Kudelkova, L., Simek, V., Jakesova, P., Machacek, M., & Zapletal, D. (2018). Selected blood biochemical indicators of Cherry Valley ducks undergoing fattening in relation to their diet and sex. *Veterinarni Medicina*, *63*(9), 420-432.

Johnson, W. P., Schmidt P. M., & Taylor, D. P. (2014). Foraging flight distances of wintering ducks and geese: a review. *Avian Conservation and Ecology*, *9*(2), 1-19.

Kremez, M., Mykhalko, O., Povod, M., Gutyj, B., Tsereniuk, O., Krygina, N., Kepkalo, I., Kuzmenko, M., & Makhno, K. (2025). Growth intensity and fattening performance of purebred pigs of different breeding lines and crossbred and hybrid animals based on them. *Scientific Papers. Series D. Animal Science*, *68*(2), 285-296.

Kuropatnicki, A. K. (2017). The tradition of goose-eating in medival and early modern England. *Studia Historyczne*, *2*(238), 57-72.

Kutay, H., Şahan, Z., Açik, İ. P., & Durmuş, M. (2024). Factors affecting meat quality in farm animals. *BIO Web of Conferences*, *85*, 01066.

Lo, B., Marty-Gasset, N., Manse, H., Canlet, C., Domitile, R., & Remignon, H. (2022). Slightly different metabolomic profiles are associated with high or low weight duck foie gras. *PLoS ONE*, *17*(6), e0255707.

Lungu, V. D., & Moise, A. E. (2025). The impact of supplementing feed with omega-3 fatty acids on the nutritional and technological characteristics of poultry meat. A review. *Scientific Papers. Series D. Animal Science, 68*(1), 234–240.

Mancinelli, A. C., Di Veroli, A., Mattioli, S., Cruciani, G., Dal Bosco, A., & Castellini, C. (2022). Lipid metabolism analysis in liver of different chicken genotypes and impact on nutritionally relevant polyunsaturated fatty acids of meat. *Scientific Reports*, *12*, 1888.

Marin, M., Drăgotoiu, D., Nicolae, C. G., & Diniță, G. (2015). Research on the influence of the oregano oil use over the productive performances and quality of duck meat. *AgroLife Scientific Journal*, *4*(2), 48-51.

Marin, M., Hodoșan, C., Diniță, G., & Nicolae, C. G. (2017). The influence of the chemical composition of maize, barley and peas hybrids on the digestibility of compound feed for pigs. *AgroLife Scientific Journal*, *6*(2), 127-132.

Massimino, W., Davail, S., Secula, A., Andrieux, C., Bernadet, M. D., Pioche, T., Ricaud, K., Gontier, K., Morisson, M., Collin, A., Panserat, S., & Houssier, M. (2020). Ontogeny of hepatic metabolism in mule ducks highlights different gene expression profiles between carbohydrate and lipid metabolic pathways. *BMC Genomics*, *21*(1), 742.

Mihai, A. L., Mulțescu, M., Negoiță, M., Horneț, G. A., Surdu, I., & Nicula, A. S. (2022). Nutritional characterization of some Romanian mountain products. *The Annals of the University Dunarea de Jos of Galați*, *Fascicle VI*, *46*(2), 104-124.

Mohammed, A. A. A., Abdel-Rahman, M. A. M., & Darwish, M. H. A. (2014). Force feeding as a stress factor on Muscovy ducks. *Journal of Advanced Veterinary Research*, *4*(4), 166-173.

Molnár, M., Nagy, I., Molnár, T., & Bogenfürst, F. (2006). Animal welfare aspects of goose liver production without force feeding: selection possibilities for behaviour forms. *Acta Agraria Kaposváriensis*, *10*(2), 223-227.

Negm, E., & Mohammed, A. (2023). Effect of stocking density on behavior, performance and some blood parameters of Muscovy ducks. *International Journal of Veterinary Sciences*, *6*(3), 17-32.

Nica, G., & Vidu, L. (2023). The stage of research on welfare requirements in livestock farms. *Scientific Papers. Series D. Animal Science*, *LXVI*(1), 317-327.

Nicolaisen, S., Langkabel, N., Thoene-Reineke, C., & Wiegard, M. (2023). Animal welfare during transport and slaughter of cattle: a systematic review of studies in the european legal framework. *Animals*, *13*(12), 1974.

Nollkaemper, A. (2023). International law and the agony of animals in industrial meat production. *European Journal of International Law*, *34*(4), 939-972.

Răducuță, I., Cristian, C., Marin, M., Bulmaga, V. D., & Călin, I. (2025). Analysis of the growth rate in different fattening systems of f1 lambs obtained by crossing french meat breed rams with local ewes from the Tsigai breed. *Scientific Papers. Series D. Animal Science*, *LXVIII*(2), 379-383.

Rehman, M. A. U., & Zulfiqar, Z. (2024). Techniques for evaluating the nutritional profile and digestibility of animal feedstuffs by different laboratory methods. *Applied Animal Science Bulletin*, *1*, 1-10.

Rochlitz, I., & Broom, D. M. (2017). The welfare of ducks during foie gras production. *Animal Welfare*, *26*, 135-149.

Saber, A. S. (2022). How ancient egyptians fed their animals. *EC Veterinary Science*, *7*(4), 22-31.

Sheta, B., Hassan, A., El-Din Sallam, A., Habbak, L., & Hyder A. (2025). Phylogenetic and lipid metabolic differences between migratory and Egyptian-domesticated Mallard ducks (*Anas platyrhynchos*). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *302*, 111814.

Skippon, W. (2013). The animal health and welfare consequences of foie gras production. *The Canadian Veterinary Journal*, *54*(4), 403-404.

Sweazea, K. L. (2022). Revisiting glucose regulation in birds – A negative model of diabetes complications. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, *262*, 110778.

Syrůček, J., Kvapilík, J., Bartoň, L., Vacek, M., & Stádník, L. (2017). Economic efficiency of bull fattening operations in the Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *65*(2), 527-536.

Temple, D., Coubourlay, V., Velarde, A., & Manteca, X. (2012). The welfare of growing pigs in five different production systems in France and Spain: assessment of health. *Animal Welfare*, *21*(2), 257-271.

Toth, Z. J. (2012). Animal Protection and Animal 'Rights' in Hungary. *Jogelméleti Szemle/ Journal of Legal Theory*, *4*, 166-175.

Tremolada, C., Bielińska, H., Minero, M., Ferrante, V., Canali, E., & Barbieri, S. (2020). Animal-based measures for the on-farm welfare assessment of geese. *Animals*, *10*(5), 890.

Tudorache, M., Custură, I., Gheorghe, A., Van, I., Bahaciu, G. V., Șuler, A. D., Diniță, G., Marin, M. P., Popescu-Micloșanu, E., & Răducuță, I. (2021). Breeding and production performances of Muscovy duck lines. Sci*entific Papers. Series D. Animal Science, 64*(1), 406-411.

Ungureanu, L. D., Nicolae, C. G., Tăpăloagă, P. R., & Marin, M. (2024). The influence of natural feed additives on the productive performance of broiler chicken - a review. *Scientific Papers. Series D. Animal Science, LXVIII*(2), 166-172.

Vlad, Ș. T., Hamzău, A., Custură, I., Chelmea, C., Ștefan, M., Uță, R., Gheciu Pîrlea, G. M., Grigore, D. M., Peț, I., Panici, G., & Tudorache, M. (2025). Rearing systems and their impact on productivity in turkey farms: a review. *Scientific Papers. Series D. Animal Science, LXVIII*(1), 302-315.

Wen, Z. G., Jiang, Y., Tang, J., Xie, M., Yang, P. L., & Gou, S. S. (2016). Effect of feed consumption levels on growth performance and carcass composition during the force-feeding period in foie gras production of male Mule ducks. *Animal*, *10*(9), 1417-1422.

Yang, W., Lang, X., Song, D., Xu, H., Zhang, C., Guo, L., & Chen, X. (2024). Comparative analysis of reproductive hormones, serum biochemical indexes and ovarian metabolites in Muscovy breeder duck at different laying stages. *Poultry Science*, *103*(12), 104370.

Zaefarian, F., Abdollahi, M. R., Cowieson, A., & Ravindran V. (2019). Avian liver: the Forgotten organ. *Animals*, *9*, 63.

Zeng, X., Zhang, K., Tian, G., Ding, X., Bai, S., Wang, J., Lv, L., Liao, Y., Xuan, Y., & Zeng, Q. (2022). Effects of fat pre-emulsification on the growth performance, serum biochemical index, digestive enzyme activities, nutrient utilization, and standardized ileal digestibility of amino acids in Pekin ducks fed diets with different fat sources. *Animals*, *12*, 2729.