Theses of Doctoral (PhD) Dissertation

INVESTIGATION OF BIOMARKERS WITH DIAGNOSTIC SIGNIFICANCE SUITABLE FOR CHARACTERIZING REDOX HOMEOSTASIS

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1. BACKGROUND AND OBJECTIVES OF THE DOCTORAL THESIS

Today, we can no longer ignore climate change. The changed conditions affect the growing season and the development cycle of plants (FAO, 2021). Thus, crop yields may decline due to heat, drought, and water shortages. Extreme weather events such as floods or droughts can cause serious damage to crops (PÖRTNER et al., 2022). At the same time, soil quality is deteriorating due to frequent erosion and desertification. In addition, the emergence of new pests and diseases threatens crops due to climate change (FAO, 2021).

Climate change also affects animal husbandry, as heat stress reduces the productivity and reproductive capacity of animals (WORLD BANK, 2021). The decline in fodder crop yields threatens the supply of feed for animals. Water shortages can cause serious problems with animal water supplies and the depletion of grazing areas. Abiotic stress also increases the risk of disease in animals (PÖRTNER et al., 2022).

When stressed, living organisms are more susceptible to disease, the biochemical background of which is a shift or disruption in redox homeostasis. Disruption of redox homeostasis leads to oxidative stress in both crop production and animal husbandry, which can cause significant economic damage. During stress, reactive oxygen species (ROS) and reactive nitrogen species (RNS) accumulate in cells, damaging lipids, proteins, and nucleic acids, thereby impairing cell function and viability. Oxidative stress, or any other type of stress, leads to a decrease in the response of the pre-organism to such an extent that it negatively affects the defense strategy of the entire organism.

Redox imbalance is both a cause and a consequence. As a vicious circle, reactive radicals induce inflammation in the body, but inflammatory responses also generate free radicals. It cannot be ignored that it determines the body's central metabolic processes, thereby influencing the functioning of living organisms. Therefore, continuous research is needed to understand and exploit the opportunities offered by knowledge of stress physiology to increase productivity. Overall, the disruption of redox homeostasis and the resulting oxidative stress have a significant negative impact on crop production and animal husbandry, reducing crop yields and quality, and impairing animal health and production indicators, leading to economic losses. Increasing stress tolerance and applying appropriate defense strategies are key to ensuring the sustainability of agricultural production.

The main objective of our research is to identify and determine the timing and measurement parameters that can be used in large-scale animal husbandry and crop production to prepare living organisms to mitigate their responses to stress.

Research objectives *in vit*ro and *in vivo* models:

- We examined morphological parameters, enzymes and small molecule antioxidants used to characterize redox homeostasis, and plant hormones in a potato model treated with in vitro ultrasound.
- Examination of redox homeostasis and carbohydrate metabolism in ROSS 308 broilers.
- Examination of carbohydrate metabolism in suckling piglets.
- Examination of a rat insulin resistance model.

2. MATERIALS AND METHODS

The scope of this paper includes the examination of samples from experiments involving potatoes, poultry, pigs, and rats. We set up two experiments to map the response of potatoes to stress.

2.1. Examination of redox-homeostasis in potato

We set up two experimental series to map the antioxidant defense system of potatoes. The two experimental series differed in terms of the method and duration of UH treatment. In both experiments, we used 4-week-old in vitro potato (Solanum tuberosum L. cv. Desirée) shoot nodules (approx. 1 cm long). The shoots were grown on MS medium (Murashige and Skoog, 1962). Thirty shoot segments with a single leaf were placed in each Magenta™ dish (77 × 77 × 97 mm, Sigma-Aldrich®, Budapest, Hungary). Ultrasonic treatment was performed immediately after placing the explants on the medium. After ultrasonic treatment, the cultures were grown for 4 weeks under a 16-hour photoperiod at a light intensity of 63.5 µmol m-2 s-1 and a temperature of 22±2 °C. The cultures were sampled at different growth stages. We examined morphological parameters: shoot length, number of nodes/shoot, fresh shoot weight, root length, fresh root weight, chlorophyll a (chl a), chlorophyll b (chl b), chl a + chl b, chl a/chla b, In addition, we examined parameters suitable for characterizing redox homeostasis: water-soluble antioxidant capacity (ACW), lipid-soluble antioxidant capacity (ACL), superoxide dismutase (SOD) using a PhotoChem device.

Oxidized glutathione (GSSG), reduced glutathione (GSH), vitamin C (AA), vitamin E, catalase (KAT), glutathione S-transferase (GST), glutathione synthase (GSS), glutathione reductase (GR), glutathione peroxidase (GPx), and ascorbate peroxidase (APX) were measured using commercially available colorimetric kits. Indole-3-acetic acid (IAA) and melatonin (MT) were determined using ELISA kits.

2.2. Examination of redox homeostasis and carbohydrate metabolism in ROSS 308 broilers

The poultry study was conducted with the approval of the Debrecen University Workplace Animal Welfare Committee (DE MÁB) (DEMAB/12-7/2015). The studies were conducted in accordance with international recommendations for the treatment of laboratory animals.

The experiment was conducted at the Small Animal Breeding Experimental Farm of the University of Debrecen. In the experiment, we introduced 180 ROSS 308 hybrids and raised them from 0 days to 42 days of age.

The 1-day-old chickens were randomly placed in 3 pens (60 birds/pen). The experiment began when the birds were 1 day old and lasted until they were 42 days old. The broilers were fed antibiotic-free, commercially available corn-soy-based basic feed (BD) according to four feeding phases: prestarter (days 1-9), starter (days 10-21), grower (days 22-31), and finisher (days 32-42). Feed and water were available ad libitum throughout the experiment.

During the experiment, blood samples were collected according to the feeding phases and the following parameters were determined:

GSH, GSSG, GR, GPx, superoxide dismutase inhibition rate, aspartate aminotransferase (AST), malondialdehyde (MDA), albumin (by colorimetric method), cysteine (Cys), homocysteine (Hcy), cysteinylglycine (Cys-Gly), γ-glutamylcysteine (γ-GC), cystine (Cyss), GSH, N-acetylcysteine (NAC) (by LC-MS method), interleukin-2 (IL-2), interleukin-6 (IL-6), interleukin-8 (IL-8), tumor necrosis factor-α (TNF-α), glucose, insulin (INS), insulin-like growth factor-1 (IGF-1), growth hormone-releasing hormone (GHRH), ghrelin, leptin (using colorimetric kit and ELISA kit).

2.3. Experiment with pigs

The pig blood samples were obtained from the pig farm of Hajdúböszörményi Mezőgazdasági Zrt. The weight of the piglets was measured three times: at birth, at 14 days of age, and at 28 days of age. Two groups were formed: the control group (n=319 piglets) was only breastfed until 10 days of age, then received prestarter dry feed. In the experimental group (n=330), the animals were fed liquid milk replacer (16.6% solution, SanAmmat F, Sano GmbH, Germany) in addition to suckling. The milk replacer was pre-mixed in a solution and poured into a 100liter container. At selection (28 days), 2 ml of blood was taken from the anterior vena cava clavalis of 22 piglets from each group. The carbohydrate metabolism profile of the piglets was determined from the blood. The concentrations of glucose, insulin, GHRH, and IGF-1 were determined from the blood samples using a colorimetric method.

2.4. Examination of carbohydrate metabolism in Wistar rats

The study was conducted on rats with the approval of the Debrecen University Animal Welfare Committee (DE MÁB) (25/2013/DEMAB). The studies were conducted in accordance with international recommendations for the treatment of laboratory animals. Male Wistar rats (n=42) were used in the study. The rats were kept in a controlled environment (22-24°C, 12-12 hour light/dark cycle). The rats were then randomly divided into six experimental groups: healthy control (K), high-fat diet control (HF), high-fat diet + 1 mg/kg diosgenin (1D), high-fat diet + 10 mg/kg diosgenin (10D), high-fat diet + 50 mg/kg diosgenin (50D), and high-fat diet + 0.2 mg/kg fenugreek seed (FG). Healthy control rats received standard laboratory chow (S8106S011 SM R/MZ+H, ssniff Spezialdi¨aten GmbH, Germany) and fresh tap water ad libitum. The animals in the other five groups received ad libitum a diet defined as high-fat and highcarbohydrate (HFD) and 5% sucrose in their drinking water. The special rodent feed (RM AFE45%FAT 20%CP 35%CHO (P)) was used as recommended by Special Diets Services (UK). The end point of the experiment was set at the seventh week of the treatment period.
After sampling, glucose, insulin, GHRH, IGF-1, triiodothyronine (T3), and thyroxine (T4) concentrations were determined in the study groups.

3. RESULTS

3.1. Antioxidant defense system response to ultrasound treatment Experiment 1

Based on the results of water-soluble antioxidant capacity (ACW), it can be concluded that lower values were measured at all sampling times compared to fat-soluble antioxidant capacity (ACL). This can be explained by the fact that the secondary metabolites synthesized by the plant are alcohol-soluble. The fat-soluble antioxidant capacity (ACL) value was similar in both UH-treated and control plants. The water-soluble antioxidant capacity showed no change, except for the values measured at 0 hours, where we observed a significant decrease as a result of ultrasonic treatment.

In the next step, we determined the concentration of small-molecule antioxidants. Twenty-four hours after treatment, their concentration increased, with the exception of vitamin E. Vitamin C decreased one week after treatment, then increased again by the fourth week. At the last sampling date, we did not observe any significant difference between the vitamin C concentrations of the treated and control plants.

GSH concentration increased within 24 hours, and a slight increase was observed as a result of UH treatment. In plants treated with UH for 4 weeks, reduced glutathione concentration was three times higher than in control plants.

Similarly, GSSG concentration was higher in samples taken 24 hours after ultrasound treatment, and the lowest values were observed in samples taken during the intensive growth phase, i.e., after one week. By the end of week 4, the oxidized glutathione concentration was significantly higher in both the control and ultrasound-treated plants. We evaluated the significantly higher GSSG level compared to the control plants as an aftereffect of UH treatment.

Vitamin E concentration did not change significantly during the first three phases of growth and development, but doubled in the control samples by the fourth week of rearing (phase 4). However, UH treatment resulted in an increase in vitamin E concentration only immediately after treatment (0-hour sampling), but no significant change was observed at later sampling times (phases 2-4) compared to the results of the control plants. It is striking that 24 hours and 1 week after UH treatment, the amount of vitamin E was significantly lower than immediately after ultrasound treatment (0-hour sampling). Comparing the vitamin E concentrations of 0hour and 4-week-old plants, we found no significant difference.

SOD, GR, and APX activity changed immediately after treatment (0 hours) and 24 hours after ultrasound treatment.

SOD activity increased significantly (from 3.96 µM to 131.24 µM) 24 hours after subculture in untreated explants. As a result of ultrasonic treatment, SOD activity increased (from 9.16 µM to 218.33 µM). Ultrasonic treatment resulted in a significant increase in SOD activity after 24 hours, 1.66 times higher than in the control samples. We observed a further increase in activity when examining 1-week-old plants (337.03 and 331.22 µM in control and UH-treated plants), which is presumably unrelated to UH treatment. After 4 weeks, SOD activity decreased. GR activity increased significantly 24 hours after UH treatment and remained 2- or 3-fold higher than control samples until the end of week 4. GST activity decreased after 24 hours and in one-week samples, due to higher SOD and/or APX activity. Increased GST activity was observed in samples from 4-week-old plants in the control group, although this increase was not significant in response to ultrasound treatment. Increased APX activity and decreased AA concentration were observed immediately after ultrasound treatment (0 hours). No significant change was observed in KAT activity. GPx activity was zero at all sampling times for both UH-treated and control plants.

3.2. The effect of ultrasonic treatment on melatonin, auxin and the antioxidant defense system

Similar to our previous experiment, we examined how the water-soluble antioxidant capacity (ACW) of control and ultrasound-treated plants changed. We did not measure any significant differences between the different groups, nor between the different sampling times within the groups. We obtained results similar to those of our previous experiment (Experiment 1: K 0h: 1.01 µg/mg ± 0.05, K 24h: 0.88 µg/mg ± 0.07, K 4 weeks: 1.16 µg/mg ± 0.01; Experiment 2: K 0h: 0.99 µg/mg ± 0.03, K 24h: 0.83 µg/mg ± 0.02, K 4 weeks: 1.33 µg/mg ± 0.018). According to our measurements of lipid-soluble antioxidant capacity (ACL), we observed significant differences only in ACL values (DOBRÁNSZKI et al., 2017a). During the intensive growth phase, in 24-hour (K 24h: 3,310 µg/mg ± 0.24) and one-week-old plants (K0 week 1: 2.98 µg/mg ± 0.04), the metabolic stress induced by growth and development was so significant that ACL values decreased significantly. The 20- and 30-minute UH treatments did not affect this trend. Comparing ACW and ACL, ACL is several times higher than ACW in control plants. The GSH concentration of the control plant gradually increased during certain growth phases (K 0h: 2.56 µg/ml ± 0.026; K 24h: 2.81 µg/ml ± 0.015; K 48h: 2.90 µg/ml ± 0.010), then decreased significantly in the one-week-old plant (K 1 week: 1.92 µg/ml ± 0.015). As a result of the UH treatments, its concentration increased after 24 hours (UH20 0h: 2.53 µg/ml ± 0.02; UH20 24h: 3.88 µg/ml ± 0.025; UH30 0h: 2.667 µg/ml ± 0.032; UH30 24h: 3.74 µg/ml

± 0.015). After 20 minutes of treatment, a decrease can be observed until the end of week 4 (UH20 48h: 3.19 µg/ml ± 0.015; UH20 1 week: 2.64 µg/ml ± 0.010; UH20 4 weeks: 1.443 µg/ml ± 0.015). After 30 minutes of UH treatment, we observed that after 1 week, similar concentration values were characteristic (UH30 1 week: 2.72 µg/ml ± 0.015) as in the 0h samples (UH30 0h: 2.66 µg/ml ± 0.032), followed by a slight, insignificant increase in concentration (UH30 week 4: 2.85 µg/ml ± 0.026).

In addition to glutathione, ascorbic acid (AA) also plays an important role in maintaining redox homeostasis in both the detoxification and regeneration phases. Based on our vitamin C results, we observed an increase in concentration in the control group after 24 hours (K 0h: 14.69 ng/ml ± 1.056; K 24h: 20.53 ng/ml ± 0.95). This was followed by a gradual decrease in the subsequent growth phases (K 48h: 10.97 ng/ml ± 0.26; K 1 week: 4.21 ng/ml ± 0.61; K 4 weeks: 6.13 ng/ml ± 0.63). It can be seen that, in addition to the metabolic stress caused by growth and development, the applied abiotic stress, i.e., ultrasound treatment, did not significantly alter the concentration of vitamin C in the plants, with values similar to those in the control group (K 24h: 20.53 ng/ml ± 0.95; UH20 24h 16.49 ng/ml ± 0.74; UH30 24h: 18.04 ng/ml ± 0.76; K 48h: 10.97 ng/ml ± 0.26; UH20 48h:11.83 ng/ml ± 1.03; UH30 48h: 10.96 ng/ml ± 0.38; K week 1: 4.21 ng/ml ± 0.61; UH20 week 1: 4.18 ng/ml ± 0.20; UH30 week 1: 5.75 ng/ml ± 0.47).

The change in glutathione synthase enzyme (GSS) activity is inversely proportional to GSH concentration. In all three groups, the enzyme is most active in 1-week-old plants (K week 1: 25.53 ng/ml ± 0.43; UH20 week 1: 20.39 ng/ml ± 0.78; UH30 week 1: 24.30 ng/ml ± 1.25). In the control group, we measured significantly higher values in the samples collected after 48 hours and 1 week K 0h: 13.35 ng/ml ± 0.89; K 48h: 16.40 ng/ml ± 1.19; K 1 week: 25.53 ng/ml ± 0.43). We also observed a significant difference at these two time points in the ultrasoundtreated groups (UH20 0h: 13.76 ng/ml ± 1.22; UH20 48h: 20.46 ng/ml ± 1.37; UH20 Week 1: 20.39 ng/ml ± 0.78; UH30 0h: 12.96 ng/ml ± 0.76; UH30 48h: 21.72 ng/ml ± 1.89; UH30 Week 1: 24.30 ng/ml ± 1.25).

We examined changes in the glutathione reductase (GR) enzyme. Glutathione reductase follows changes in GSH concentration in the control group. The 20-minute UH treatment did not affect the direction of quantitative changes, showing a similar trend. However, compared to the results obtained for the control plants, GR activity was significantly reduced. The 30minute UH treatment, which was considered severe abiotic stress, increased GR activity 48 hours after the ultrasound treatment (UH30 48h: 18.84 mU/ml ± 0.15), but was unable to increase it in the subsequent growth phases.

When examining changes in ascorbate peroxidase (Apx) concentration, it is striking that in all three groups, the Apx concentration of one-week-old plants increases significantly (K 0h: 36.71 ng/ml ± 0.47; K 1 week: 67.06 ng/ml ± 0.62; UH20 0h: 34.44 ng/ml ± 0.76; UH 1 week: 71.82 ng/ml ± 0.44; UH30 0h: 37.63 ng/ml ± 0.58; UH30 week 1: 67.52 ng/ml ± 0.68). The same pattern can be observed for ascorbate peroxidase as for glutathione synthase and glutathione, inversely following the values of ascorbic acid concentration. While the ascorbic acid concentration shows a significant decrease in 1-week-old plants, the glutathione synthase concentration increases significantly compared to the values measured at other sampling times in all three groups.

Based on the results of changes in superoxide dismutase enzyme activity, it can be concluded that in the control group, 24 and 48 hours (K 24h: 183 U/ml ± 4.57; K 48h: 403.8 U/ml ± 3.93) compared to 0 hours (K 0h: 114.6 U/ml ± 5.28). SOD activity decreased in 1-week-old plants (K 1 week: 233.7 U/ml ± 5.04), and a further decrease was observed in 4-week-old samples (K 4 weeks: 135.5 U/ml ± 2.27). This trend did not change significantly when the plants were subjected to 20 minutes of ultrasound treatment. A significant increase in SOD activity was detected in 1-week-old plants in both the control (K 1 week: 233.7 U/ml ± 5.04) and 20 (UH20 1 week: 309.9 U/ml ± 1.95) and 30 minutes (UH30 1 week: 326.3 U/ml ± 3.49) UH treatment. The 4-week samples showed SOD activity similar to the 0-hour values (K 0h: 114.6 U/ml ± 5.28; K week 4: 135.5 U/ml ± 2.27; UH20 0h: 138.9 U/ml ± 3.35; UH20 week 4: 110.9 U/ml ± 3.63; UH30 0h: 105.6 U/ml ± 6.52; UH week 4: 112.9 U/ml ± 3.98).

We measured changes in indole-3-acetic acid (IAA) concentration. In the control plants, IAA concentration did not change in the first 24 hours (K 0h: 65.41 ng/ml ± 1.53; K 24h: 66.76 ng/ml ± 3.46), but its concentration decreased in the other growth phases (K 48h: 52.75 ng/ml ± 1.12; K 1 week: 54.32 ng/ml ± 1.39; K 4 weeks: 50.78 ng/ml ± 4.70). There was no change in the 1-week samples compared to the initial phase. However, the 20-minute UH treatment had a modulating effect, significantly increasing the concentration in the 4-week-old plants (UH20 0h: 56.39 ng/ml ± 3.53; UH20 week 4: 83.32 ng/ml ± 4.28). The 30-minute ultrasound treatment did not cause an increase in concentration in the 1-week-old plants, but caused a significant increase in all other phases (UH30 0h: 58.58 ng/ml ±.3.21; UH30 24h: 77.64 ng/ml ± 1.62; UH30 48h: 76.65 ng/ml ± 1.19; UH30 Week 4: 80.53 ng/ml ± 1.11).

The melatonin concentration in the control group differs significantly from the 0h sample in all growth phases (K 0h: 5.88 ng/g ± 0.01; K 24h: 8.62 ng/g ± 0.02; K 48h: 5.18 ng/g ± 0.06; K 1 week: 5.47 ng/g ± 0.03; K 4 weeks: 6.52 ng/g ± 0.05). Melatonin concentration increased in 24hour plants and then decreased in 48-hour and one-week samples compared to 0-hour

samples. After 20 minutes of ultrasound treatment, melatonin levels increased in 24-hour samples (UH20 24h: 4.42 ng/g ± 0.02) compared to 0-hour samples (UH20 0h: 4.14 ng/g ± 0.01). Both 20- and 30-minute UH treatments reduced melatonin concentrations in later growth phases (48 hours and 1 week; UH20 48h: 3.47 ng/g ± 0.03; UH20 1 week: 3.54 ng/g ± 0.05; UH30 48h: 3.44 ng/g ± 0.01; UH30 1 week: 3.89 ng/g ± 0.03), and then increased it in 4-week-old plants (UH 20 4 weeks: 4.40 ng/g ± 0.01; UH30 4 weeks: 5.92 ng/g ± 0.03).

Our results are consistent with general stress response models, which describe coordinated enzymatic and non-enzymatic defenses as a common outcome of abiotic stress (KHAN ET AL., 2020; REHAMAN et al., 2021).

The interaction between melatonin and auxin levels is consistent with broader models of hormonal interactions during stress adaptation (ZHANG et al., 2022).

3.3. The antioxidant protection system and carbohydrate metabolism of poultry

Genetic selection of broiler chickens promotes the animals' susceptibility to biotic and abiotic stress factors.

The effect of oxidative stress on physiological functions has been the focus of numerous studies for decades. Its characteristic parameters are (i) enzymes (SOD, KAT, GTS, and GPx), (ii) small molecule antioxidants (vitamins E and C and glutathione), and (iii) heat shock proteins, which allow us to examine the role of a given substance or environmental factor in maintaining redox homeostasis (Babinszky et al., 2019; Rahman, 2007). However, the dynamic characteristics of redox homeostasis must be taken into account, which means that measurements taken at a single point in time cannot be used to draw accurate conclusions about the oxidant/pro-oxidant balance and pathological conditions. The state of redox homeostasis must be monitored throughout the entire life cycle, which allows for comparison between different stages of development. In the case of broilers, it is not possible to determine the water- and fat-soluble antioxidant capacity from plasma using the method described above, as no secondary metabolites are formed that support the animal's antioxidant defense system. In poultry, MDA, thiols, albumin, and albumin saturation can be used for this purpose.

In the samples taken at the first time point, the plasma malondialdehyde (MDA) concentration was 187 nmol/ml ± 1.57. This value decreased in the plasma of animals at 8 (162.6 nmol/ml ± 0.10) and 21 days (144.5 nmol/ml ± 0.26), then increased significantly by day 32 (229.3 nmol/ml ± 0.23).

In contrast, the concentration of vitamin E in blood plasma was highest on day 21 (26.6 ng/ml ± 0.16), but decreased by the end of the experiment (day 42: 24.20 ng/ml ± 0.15). On day 21, the amount of α-tocopherol decreased with the increase in MDA concentration, although this was not significantly detectable.

The GSH concentration showed a continuous, significant decrease during the experiment. On day 3, it was 10.45 μM ± 0.36, by day 21 (4.49 μM ± 0.15) it had decreased by half, and by the end of the rearing period it showed a further decrease (3.15 μM ± 0.13). Hydrogen peroxide was eliminated by GPx with the help of GSH. Even with intense glutathione reductase activity, the glutathione concentration in 21-day-old birds decreased by almost half, indicating significant oxidative stress.

Similar to MDA, the concentration of vitamin C in blood plasma was lowest on day 21 (9.57 nmol/ml ± 0.28) and then increased significantly by the end of the experiment (28.34 nmol/ml ± 0.44).

The SOD [EC 1.15.1.1] inhibition rate decreased significantly by day 21 (49.26% ± 0.26), increased slightly by day 32 (55.55% ± 0.31), and decreased again at the end of the experimental period.

When examining the DTNB-Tiol concentration, it decreased significantly in plasma on days 21 and 32 (day 21: 2188 μM ± 88.36; day 32: 1555 μM ± 43.49), it decreased significantly in plasma, then rose slightly by day 42 (2353 μM ± 34.40), and we measured a value similar to that measured on day 21.

When evaluating the albumen concentration, we observed a continuous significant increase during the experimental period. Except for day 21, when a slight decrease was detected (day 3: 12.25 g/l ± 0.08; day 8: 15.56 g/l ± 0.13; day 21: 14.43 g/l ± 0.24, day 32: 15.29 g/l ± 0.87; day 42: 15.92 g/l ± 0.09.

The decrease in glutathione peroxidase (GPx) activity had an adverse effect on regeneration and detoxification pathways, resulting in an increase in the concentration of vitamin E measurable in blood plasma.

GPx activity decreased on day 21 (40.28 mU/mL ± 0.21) and then increased significantly until the end of the experiment (day 42: 59.03 mU/mL ± 0.11).

Glutathione reductase (GR) activity showed similar values on day 8 (54.56 mU/mL ± 0.11) and day 21 (53.25 mU/mL ± 0.13). Later, an increase was observed on day 32 (79.44 mU/ml ± 0.33). The activity measured at the previous time point remained unchanged until the end of the rearing period (79.30 mU/ml ± 0.09). The GSH level decreased, although the activity of conjugated glutathione-cleaving GR increased significantly and continuously over the 42 days.

We measured the concentration of plasma thiols and disulfides (TTD). At each time point, we examined cysteine (Cys) homeostasis and the participants of the transsulfuration pathway (TSP). During TTD measurements, we focused on Cys homeostasis and TSP participants. The most marked decrease in GSH levels was observed on day 21 (4930 ng/mL ± 0.13), which continued to decrease until the end of the experimental period (day 42: 3786 ng/mL ± 0.20). This contrasted with the concentration of γ-glutamylcysteine (γ-GC), which is a precursor of glutathione (BRAIDY et al., 2019). The concentration of γ-GC increased by day 8 (9072 ng/ml ± 018) and remained virtually unchanged thereafter.

Our measurements showed a significant increase in cysteine (Cys) levels in fast-growing broiler chickens on day 8 (9740 ng/ml ± 0.2), and Cys levels remained high throughout the birds' entire life cycle.

The significant change in GSH and cystine (Cyss) concentrations (NTE and GUNN, 2021) was consistent with the change in cysteinylglycine (Cys-Gly) disulfide levels. The concentration of cystine (Cyss), similar to reduced glutathione, increased by day 8 (136 ng/ml ± 0.16) and then decreased until the end of the rearing period (day 21: 120 ng/ml ± 0.12; day 32: 112 ng/ml ± 0.20; day 42: 96 ng/ml ± 0.14), while the amount of Cys-Gly first decreased and then increased. Homocysteine Hcy levels more than doubled on day 8 (day 3: 5866 ng/ml ± 0.15; day 8: 13866 ng/ml ± 013) more than doubled and remained high until day 42 (9876 ng/ml ± 0.17) compared to day 3.

The concentration of N-acetylcysteine (NAC) varies significantly during certain growth periods, with a continuous decrease observed over 42 days (188 ng/ml ±.0.20) compared to day 3 (396 ng/ml ±.0.19). The concentration of N-acetylcysteine (NAC) varies significantly during certain growth periods, with a continuous decrease observed over 42 days (188 ng/ml ±.0.20) compared to day 3 (396 ng/ml ±.0.19).

The decisive role of free and bound thiols has already been proven in human studies, but there is still no suitable method for measuring them. The new method published by FU et al. (2019) provides a reliable and reproducible procedure for testing all types of thiol compounds. Cytokine levels rose in parallel with the growth of the birds. From day 21 onwards, we observed an approximately fourfold increase in all parameters.

The concentration of interleukin-2 was 1.26 ng/l ± 0.14 on day 3 of the experiment, then rose to 8.76 ng/l ± 0.98 on day 21. On day 42 (12.84 ng/l ± 2.67), we measured an even higher concentration in the birds' plasma. A similar trend can be observed for interleukin-6, interleukin-8, and tumor necrosis factor-α. Our results also showed that the concentration of these markers was extremely high on day 42, indicating severe inflammation in the animals.

DNA, lipids, and proteins broken down by oxidative stress lead to necrosis, loss of hepatocytes, and an increased inflammatory response. Progressive liver fibrosis and chronic inflammation may develop if the primary disease and persistent stimuli are not controlled, which, together with necrosis, are characteristic of fibrotic liver diseases (CZAJA, 2014). This was confirmed by our results from 21-day-old birds, namely, the level of the necrotic enzyme aspartate aminotransferase (AST) was significantly elevated. The plasma (AST) concentration increased significantly on day 21 (day 3: 125.8 U/l ± 2.92; day 21: 235.4 U/l ± 3.57), then decreased by the end of the experiment (day 42: 170 U/l ± 4.65).

In addition to elevated inflammatory parameters, histological sections clearly showed structural changes in the liver. Among other things, hydropic degeneration and the appearance of inflammatory cells were observed (XING et al., 2021). Based on the histological image of the liver, fatty degeneration of the liver was characteristic in 42-day-old animals, and the number of lipid deposits increased significantly. This was also reflected in the number of Mallory bodies, which indicates the aggregation of damaged intermediate filaments (JENSEN and GLUUD, 1994a, 1994b).

Similar trends to those observed in our results are reported by SURAI et al. (2019) and SAHIN et al. (2023), according to which intensive growth, environmental stress, or metabolic load consistently increases the levels of reactive oxygen species and challenges antioxidant defense systems (SAHIN et al., 2023; SURAI et al., 2019).

3.3.1. Changes in the carbohydrate metabolism of broiler chicken

We examined changes in carbohydrate metabolism during intensive growth. Glucose is the main precursor of adenosine triphosphate (ATP), and thus the main source of energy for cells, playing a key role in nutrient supply, mobilization, and storage processes.

Looking at our measurement results, we can see that plasma glucose levels didn't change much over the 42-day period. At the beginning of the rearing period, we measured a glucose concentration of 15.53 mmol/l ± 2.04, and on the 42nd day, 14.39 mmol/l ± 2.10.

The plasma insulin concentration on day 42 was 13.21 mU/L ± 2.79. The result measured at the end of the rearing period is significantly higher than the concentrations measured on day 8 (7.97 mU/l ± 0.53), day 21 (7.37 mU/l ± 0.61), and day 35 (8.67 mU/l ± 1.12).

On days 35 (342.5 pg/mL ± 40.56) and 42 (359.1 pg/mL ± 41.14), plasma IGF-1 concentrations increase significantly compared to other sampling times after day 21.

The concentration of GHRH in the plasma of birds decreased significantly by day 21 (88.95 pg/ml ± 5.47) and then increased significantly by the end of the rearing period (day 42, 134.6 ± 4.44) compared to the results of the first three sampling dates.

Plasma growth hormone concentration, which shows a downward trend (day 3: 249.7 pg/ml ± 64.11, day 8: 177.7 pg/ml ± 43.13, day 21: 161.9 pg/ml ± 32.24, day 35 173.3 pg/ml ± 37.53, day 42 158.9 pg/ml ± 22.05), but no significant difference was detected between feed changes. Based on our measurements, it can be said that ghrelin concentration decreases by day 42 (day 3: 1349 pg/ml ± 27.09; day 8: 1347 pg/ml ± 54.48; day 21 1297 pg/ml ± 226.9; day 32 1365 pg/ml ± 85.39; day 42 1135 pg/ml ± 24.33), but there is no significant difference between the different sampling times.

Significantly higher leptin concentrations were measured in animals at 8 days (325.5 pg/ml ± 18.91) and 42 days (448.6 ± 10.47) compared to the values obtained at other sampling times. Our results are consistent with studies on the transition to reduced insulin sensitivity, or "insulin resistance," during late growth. Stable glucose and rising insulin levels are comparable to scientific work on broiler chicken feeding, which shows that plasma glucose concentrations can remain unchanged in response to macronutrients, even when endocrine/metabolic regulation changes (NIJDAM et al., 2006).

3.4. The effect of supplementary pig milk replacer on carbohydrate metabolism in suckling piglets

We observed significant differences in all parameters measured in the group receiving milk replacer compared to the control group, except for plasma glucose concentration. Insulin and IFG-1 concentrations were significantly higher in animals raised on the milk feeding system, while GHRH concentrations showed a significantly higher deviation in the control group. Our results are very similar to those of the classic milk replacer performance test, which showed that supplemental milk replacer increased the average weaning weight of piglets and the total weaning weight of the litter, i.e., our growth results are consistent with what the study interprets as hormonally supported anabolism (AZAIN et al., 1996b). Thus, although Azain et al. (1996) report primarily on performance endpoints rather than hormonal changes, the overall conclusion is the same: supplementation improves pre-weaning growth (AZAIN et al., 1996b).

3.5. Investigation of the effect of diosgenin and a biological matrix based on fenugreek in a rat-based insulin resistance model

We used **hyperinsulinemic euglycemic glucose clamp (HEGC)** to examine the effects of fenugreek and diosgenin on peripheral insulin sensitivity and changes in hormones regulated by the hypothalamic-pituitary axis, such as growth hormone, insulin, IGF-1, T3, and T4. During the HEGC test, high insulin levels and euglycemic glucose levels are maintained continuously. Minute 0 indicates the start of the surgery (before the start of glucose and insulin infusion), and minute 120 indicates the end of the surgery. Samples were taken from all animals.

Fasting glucose levels did not show any statistically significant differences between the groups. In the steady state, since blood glucose levels are artificially maintained in a euglycemic state in HEGC, there were no significant differences between the groups.

There was no statistically significant difference in fasting plasma insulin levels. At steady state, animals on the 1D diet (high-fat diet + 1 mg/kg diosgenin) showed a significant decrease (109.5 µIU/l ± 15.14) compared to healthy controls (K) (151.4 µIU/l ± 22.8) and high-fat controls (HF) (174.4 µIU/l ± 15.16). In the FG (high-fat diet + 0.2 mg/kg fenugreek seeds) group (117.5 µIU/l ± 8.901) showed a statistically significant decrease compared to the HF (high-fat diet) group (174.4 µIU/l ±15.16). However, animals in the 10D group (high-fat diet + 10 mg/kg diosgenin) showed a significant increase in insulin levels (246.1 µIU/l ± 7.605) compared to both the K (151.4 µIU/l ± 22.8) and HF animals (174.4 µIU/l ± 15.16).

At the start of the surgery, IGF-1 levels did not show any statistically significant differences between the groups. However, in the steady state of HEGC, IGF-1 levels increased significantly in the HF, 1D, 10D, and FG groups compared to the corresponding 0-minute values (**HF0**: 226.9 ng/mL ± 18.09, **HF120**: 278 ng/mL ± 21.39; **1D0**: 216.8 ng/ml ± 28.99, **1D120**: 310.7 ng/ml ± 20.03; **10D0**: 223.2 ng/ml ± 16.08, **10D120**: 275.7 ng/ml ± 25.07; **FG0**: 209.8 ng/ml ± 26.30, **FG120**: 281.7 ng/ml ± 33.14).

In the fasting state, all diosgenin groups (**1D0**: 2396 pg/ml ± 236.8; **10D0**: 2047 pg/ml ± 254.7; **50D0**: 2329 pg/ml ± 121.8) and the FG group (1443 pg/ml ± 204.5) showed a significant increase in GH levels compared to HF (1523 pg/ml ± 316.2) animals. However, in the steady state of HEGC, GH levels increased in healthy controls (3107 pg/ml ± 411.1) and in the HF group (2733 pg/ml ± 204.9), although no significant difference was observed compared to the corresponding 0-minute value. In the groups receiving diosgenin supplementation, GH levels showed a dose-dependent decrease. In the 10D120 (1660 pg/ml ± 435.5) and 50D120 (high-

fat diet +5 0mg/kg diosgenin) (1499 pg/ml ± 222.4), the decrease was statistically significant compared to healthy controls (3107 pg/ml ± 411.1). In the 50D group, we also observed a significant decrease compared to the 0-minute value (**50D0**: 2329 pg/ml ± 121.8, **50D120**: 1499 pg/ml ± 222.4). Alfalfa treatment (FG) showed a significant decrease in GH levels at steady state compared to both the K and HF groups (**K120**: 3107 pg/ml ± 411.1; **HF120**: 2733 pg/ml ± 204.9; **FG120**: 1289 pg/ml ± 329.2).

The fasting T3 level decreased significantly in all groups compared to the healthy control group (**K0**: 1.125 ng/ml ± 0.28; **HF0**: 0.5986 ng/ml ± 0.159, **1D0**: 0.6557 ng/ml ± 0.112; **10D0**: 0.7443 ng/ml ± 0.123; **50D0**: 0.8086 ng/ml ± 0.129; **FG0**: 0.8343 ng/ml ± 0.1525). At steady state, T3 decreased in the K 120 group, but there was no statistically significant difference. Rats treated with diosgenin showed a significant increase compared to the corresponding 0-minute values (**1D0**: 0.6557 ng/ml ± 0.112, **1D120**: 1.029 ng/ml ± 0.13; **10D0**: 0.7443 ng/ml ± 0.123, **10D120**: 1.070 ng/ml ± 0.14; **50D0**: 0.8086 ng/ml ± 0.129, **50D120**: 1.21 ng/ml ± 0.22). In the 50D 120 (1.21 ng/ml ± 0.22) group, T3 levels were also significantly elevated compared to the steady state values of HF 120 (0.7457 ng/ml ± 0.13) animals.

The FG 0 (20.86 ng/ml ± 2.30) group showed a statistically significant increase in fasting T4 levels compared to the K 0 (12.06 ng/ml ± 2.43) and HF 0 (9.15 ng/ml ± 1.39) groups. During the stationary period of HEGC, T4 levels increased in animals treated with diosgenin compared to baseline values, but only in the 10D 0 (7.99 ng/ml ± 1.16) and 10D 120 (14.24 ng/ml ± 0.92) groups. However, in rats treated with fenugreek seeds, T4 levels showed a significant decrease compared to the elevated fasting values (**FG0**: 20.86 ng/ml ±2.30, **FG120**: 10.59 ng/ml ± 1.42).

The trend of improved insulin action without significant changes in glucose levels is comparable to studies in which fenugreek/diosgenin improves metabolic control primarily through insulin sensitivity, inflammation, and downstream metabolic regulation, rather than just acute reduction in glucose levels (FULLER and STEPHENS, 2015; UEMURA et al., 2010).

Naidu et al. (2015) reported that diosgenin reduced blood glucose, insulin levels, and insulin resistance in diabetic rats and improved tissue/plasma lipid profiles, which is consistent with our findings (NAIDU et al., 2015). SARAVANAN et al. (2014) concluded that diosgenin reduces the activity of key carbohydrate metabolism enzymes, supporting the general comparability that diosgenin can favorably modify glucose metabolism through the regulation of hepatic metabolic pathways (SARAVANAN et al., 2014).

4. NEW SCIENTIFIC RESULTS

1. Based on my comparative studies, the direct enzymatic pathway and the measurement of small molecule antioxidants are suitable for characterizing redox homeostasis in both autotrophic and heterotrophic organisms. In the case of potatoes, we examined 11 and 10 parameters at four different time points during in vitro organogenesis in two experiments. The antioxidant defense system and the plant's response to stress can be well characterized by the changes in the parameters we measured during growth and development. In the case of broiler chickens, we examined 16 parameters at 5 different time points, the results of which provide a comprehensive picture of the broiler chicken's response to metabolic stress.
2. Melatonin plays a central role in the plant antioxidant defense system. Based on the results of correlation analysis, it showed a negative correlation with reduced glutathione, superoxide dismutase, and vitamin C, and a positive correlation with fat-soluble antioxidant capacity.
3. Among vertebrates, we have demonstrated that albumin and its saturation level play a central role in the redox balance of plasma in birds. Albumin is capable of reversibly binding glutathione and homocysteine to form mixed disulfides. In our evaluation of the results, albumin showed a correlation of 66.67% with thiol components. We observed a positive correlation between albumin and cysteine, homocysteine, and γglutamylcysteine, and a negative correlation with n-acetylcysteine.
4. Modifying the method used by Fu et al. (2018), the concentration of total thiols and disulfides in plasma was determined at five time points during the 42-day rearing period of broiler chickens: glutathione concentration decreased by 40.41%, and nacetylcysteine concentration decreased by 52.52% by the end of the rearing period. Cysteine increased by 27% on day 21, γ-glutamylcysteine increased by 35.2%, and then their concentrations decreased by 5.6% and 3.1% on day 42. Cysteinylglycine concentration decreased by 24.9% by day 21, then increased by 36.2% by the end of the rearing period. The concentration of homocysteine increased by 132% by day 21, then was 68% higher on day 42 compared to the value measured at the start of the rearing period. Based on our measurement results, intensive growth in broiler chickens leads to hyperhomocysteinemia and damage to the transsulfuration pathway. Homocysteine concentration was consistently high in the plasma of birds.
5. Redox balance is closely related to the transsulfuration pathway, and damage to it leads to the development of non-alcoholic fatty liver syndrome. Based on our measurements,

we found correlations among the 12 parameters examined. There is a negative correlation between glutathione reductase activity and glutathione. There is a positive correlation between cysteinylglycine and n-acetylcysteine concentrations. We found a negative correlation between SOD inhibition rate, homocysteine, and γglutamylcysteine, and a positive correlation between glutathione and n-acetylcysteine. Furthermore, we found a positive correlation between vitamin C and glutathione, cysteinylglycine, and a negative correlation between vitamin C and n-acetylcysteine. A characteristic parameter of non-alcoholic fatty liver disease is aspartate aminotransferase, which shows a significant increase during growth and development. In our measurements, its concentration increased by 87.1% by day 21.

6. Among secondary plant metabolites, we confirmed that diosgenin regulates carbohydrate metabolism in addition to redox balance. T3 concentration decreased in the treated groups compared to the control (0-minute sampling): 1 mg/kg diosgenin by 46.7%, 10 mg/kg diosgenin by 33.8%; 50 mg/kg diosgenin by 28.1%. Growth hormone was present in significantly lower concentrations in the stationary phase than in the control group, 1 mg/kg diosgenin by 37.7%, 10 mg/kg diosgenin by 46.57%, 50 mg/kg diosgenin by 51.7%, and 0.2 mg/kg fenugreek seed by 58.5%.

5. PRACTICAL APPLICATION RESULTS

Based on our findings regarding the antioxidant defense system and redox homeostasis presented in this paper, we have identified key parameters that may help plants and animals defend themselves against stress factors:

1. Our findings on the ascorbate-glutathione cycle and melatonin-auxin help in managing extreme agricultural conditions caused by stress. Melatonin can be used as a biostimulant, and our findings can help improve the application protocol.
2. During the examination of the redox homeostasis of broiler chickens, it was noticeable that on day 21, there was increased oxidative stress in the animals' bodies, which can be linked to rapid, significant weight gain. Our results contribute to the improvement of feeding protocols and the timely use of feed supplements with antioxidant properties.
3. A tiolok és diszulfidok közül a homocisztein, cisztein, valamint az AST meghatározása diagnosztikus jelentőségű.
4. The test results for fenugreek seeds and diosgenin in insulin-resistant rat models provide evidence for the potential therapeutic use of fenugreek.

6. REFERENCES

1. AZAIN, M.J., TOMKINS, T., SOWINSKI, J.S., ARENTSON, R.A., JEWELL, D.E., 1996. Effect of supplemental pig milk replacer on litter performance: seasonal variation in response. J Anim Sci 74, 2195–2202. https://doi.org/10.2527/1996.7492195x
2. BABINSZKY, L., HORVÁTH, M., REMENYIK, J., VERSTEGEN, M.W.A., 2019. The adverse effects of heat stress on the antioxidant status and performance of pigs and poultry and reducing these effects with nutritional tools. Poultry and pig nutrition: Challenges of the 21st century 187–208. https://doi.org/10.3920/978-90-8686-884-1_8
3. BRAIDY, N., ZARKA, M., JUGDER, B.-E., WELCH, J., JAYASENA, T., CHAN, D.K.Y., SACHDEV, P., BRIDGE, W., 2019. The Precursor to Glutathione (GSH), γGlutamylcysteine (GGC), Can Ameliorate Oxidative Damage and Neuroinflammation Induced by Aβ40 Oligomers in Human Astrocytes. Frontiers in Aging Neuroscience 11.
4. CZAJA, A.J., 2014. Hepatic inflammation and progressive liver fibrosis in chronic liver disease. World J Gastroenterol 20, 2515–2532. https://doi.org/10.3748/wjg.v20.i10.2515
5. DOBRÁNSZKI, J., ASBÓTH, G., HOMOKI, D., BÍRÓ-MOLNÁR, P., TEIXEIRA DA SILVA, J.A., REMENYIK, J., 2017. Ultrasonication of *in vitro* potato single node explants: Activation and recovery of antioxidant defence system and growth responses. Plant Physiology and Biochemistry 121, 153–160. https://doi.org/10.1016/j.plaphy.2017.10.022
6. FAO, 2021. Climate-smart agriculture case studies 2021. FAO;
7. FULLER, S., STEPHENS, J.M., 2015. Diosgenin, 4-Hydroxyisoleucine, and Fiber from Fenugreek: Mechanisms of Actions and Potential Effects on Metabolic Syndrome. Advances in Nutrition 6, 189–197. https://doi.org/10.3945/an.114.007807
8. JENSEN, K., GLUUD, C., 1994a. The mallory body: Morphological, clinical and experimental studies (part 1 of a literature survey). Hepatology 20, 1061–1077. https://doi.org/10.1002/hep.1840200440
9. JENSEN, K., GLUUD, C., 1994b. The mallory body: Theories on development and pathological significance (part 2 of a literature survey). Hepatology 20, 1330–1342. https://doi.org/10.1002/hep.1840200534
10. KHAN, A., NUMAN, M., KHAN, A.L., LEE, I.-J., IMRAN, M., ASAF, S., ALHARRASI, A., 2020. Melatonin: Awakening the Defense Mechanisms during Plant Oxidative Stress. Plants 9, 407. https://doi.org/10.3390/plants9040407
11. MURASHIGE, T., SKOOG, F., 1962. A Revised Medium for Rapid Growth and Bio Assays with Tobacco Tissue Cultures. Physiologia Plantarum 15, 473–497. https://doi.org/10.1111/j.1399-3054.1962.tb08052.x
12. NAIDU, P.B., PONMURUGAN, P., BEGUM, M.S., MOHAN, K., MERIGA, B., RAVINDARNAIK, R., SARAVANAN, G., 2015. Diosgenin reorganises hyperglycaemia and distorted tissue lipid profile in high-fat diet–streptozotocin-induced diabetic rats. Journal of the Science of Food and Agriculture 95, 3177–3182. https://doi.org/10.1002/jsfa.7057
13. Nijdam, E., Lambooij, E., Nabuurs, M.J.A., Decuypere, E., Stegeman, J.A., 2006. Influences of Feeding Conventional and Semisynthetic Diets and Transport of Broilers on Weight Gain, Digestive Tract Mass, and Plasma Hormone and Metabolite Concentrations. Poultry Science 85, 1652–1659. https://doi.org/10.1093/ps/85.9.1652

14. NTE, I., GUNN, H., 2021. Cysteine in Broiler Poultry Nutrition. https://doi.org/10.5772/intechopen.97281
15. PÖRTNER, H.-O., ROBERTS, D.C., TIGNOR, M.M.B., POLOCZANSKA, E.S., MINTENBECK, K., ALEGRÍA, A., CRAIG, M., LANGSDORF, S., LÖSCHKE, S., MÖLLER, V., OKEM, A., RAMA, B. (Eds.), 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
16. RAHMAN, K., 2007. Studies on free radicals, antioxidants, and co-factors. Clin Interv Aging 2, 219–236.
17. REHAMAN, A., MISHRA, A.K., FERDOSE, A., PER, T.S., HANIEF, M., JAN, A.T., ASGHER, M., 2021. Melatonin in Plant Defense against Abiotic Stress. Forests 12, 1404. https://doi.org/10.3390/f12101404
18. SAHIN, K., SAHIN, E., DEEH, P.B.D., KAYRI, V., ORHAN, C., SAHIN, N., 2023. Role of the antioxidant defence system and transcription factors in preventing heat stress in poultry: a dietary approach. World's Poultry Science Journal 79, 651–687. https://doi.org/10.1080/00439339.2023.2234380
19. SARAVANAN, G., PONMURUGAN, P., DEEPA, M.A., SENTHILKUMAR, B., 2014. Modulatory Effects of Diosgenin on Attenuating the Key Enzymes Activities of Carbohydrate Metabolism and Glycogen Content in Streptozotocin-Induced Diabetic Rats. Canadian Journal of Diabetes 38, 409–414. https://doi.org/10.1016/j.jcjd.2014.02.004
20. SURAI, P.F., KOCHISH, I.I., FISININ, V.I., KIDD, M.T., 2019. Antioxidant Defence Systems and Oxidative Stress in Poultry Biology: An Update. Antioxidants (Basel) 8, 235. https://doi.org/10.3390/antiox8070235
21. UEMURA, T., HIRAI, S., MIZOGUCHI, N., GOTO, T., LEE, J.-Y., TAKETANI, K., NAKANO, Y., SHONO, J., HOSHINO, S., TSUGE, N., NARUKAMI, T., TAKAHASHI, N., KAWADA, T., 2010. Diosgenin present in fenugreek improves glucose metabolism by promoting adipocyte differentiation and inhibiting inflammation in adipose tissues. Molecular Nutrition & Food Research 54, 1596–1608. https://doi.org/10.1002/mnfr.200900609
22. WORLD BANK, 2021. Climate change adaptation in the agriculture sector in Europe [WWW Document]. URL https://www.eea.europa.eu/en/analysis/publications/ccadaptation-agriculture/cc-adaptation-agriculture (accessed 3.11.25).
23. XING, T., PAN, X., ZHANG, L., GAO, F., 2021. Hepatic Oxidative Stress, Apoptosis, and Inflammation in Broiler Chickens With Wooden Breast Myopathy. Front Physiol 12, 659777. https://doi.org/10.3389/fphys.2021.659777
24. ZHANG, M., GAO, C., XU, L., NIU, H., LIU, Q., HUANG, Y., LV, G., YANG, H., LI, M., 2022. Melatonin and Indole-3-Acetic Acid Synergistically Regulate Plant Growth and Stress Resistance. Cells 11, 3250. https://doi.org/10.3390/cells11203250

7. PUBLICATION LIST

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A PhD értekezés alapjául szolgáló közlemények

Idegen nyelvű tudományos közlemények hazai folyóiratban (1)

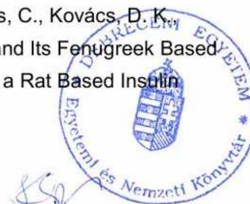
1. **Pesti-Asbóth, G.**, Novotniné Dankó, G., Győri, Z., Stündl, L., Szarvas, M. M., Gálné Remenyik, J.: The effect of supplemental pig milk replacer on carbohydrate metabolism: a review. *Agrártud. közl. 75* (2), 67-71, 2018. ISSN: 1587-1282. DOI: http://dx.doi.org/https://doi.org/10.34101/actaagrar/75/1648

Idegen nyelvű tudományos közlemények külföldi folyóiratban (4)

2. **Pesti-Asbóth, G.**, Szilágyi, E., Bíróné Molnár, P., Oláh, J., Babinszky, L., Czeglédi, L., Cziáky, Z., Paholcsek, M., Stündl, L., Gálné Remenyik, J.: Monitoring physiological processes of fast-growing broilers during the whole life cycle: Changes of redox-homeostasis effected to trassulfuration pathway predicting the development of non-alcoholic fatty liver disease. *PLoS One. 18* (8), 1-28, 2023. ISSN: 1932-6203. DOI: http://dx.doi.org/10.1371/journal.pone.0290310 IF: 2.9

3. **Pesti-Asbóth, G.**, Bíróné Molnár, P., Forgács, I. N., Gálné Remenyik, J., Dobránszki, J.: Ultrasonication affects the melatonin and auxin levels and the antioxidant system in potato in vitro. *Front. Plant Sci. 13*, 1-15, 2022. EISSN: 1664-462X. DOI: http://dx.doi.org/10.3389/fpls.2022.979141 IF: 5.6

4. Kiss, R., **Pesti-Asbóth, G.**, Szarvas, M. M., Stündl, L., Cziáky, Z., Hegedűs, C., Kovács, D. K., Badale, A., Máthé, E., Szilvássy, Z., Gálné Remenyik, J.: Diosgenin and Its Fenugreek Based Biological Matrix Affect Insulin Resistance and Anabolic Hormones in a Rat Based Insulin Resistance Model. *Biomed Res. Int. 2019*, 1-13, 2019. ISSN: 2314-6133. DOI: http://dx.doi.org/10.1155/2019/7213913 IF: 2.276



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5. Dobránszki, J., **Pesti-Asbóth, G.**, Homoki, D., Bíróné Molnár, P., Teixeira da, S. J. A., Gálné Remenyik, J.: Ultrasonication of in vitro potato single node explants: Activation and recovery of antioxidant defence system and growth responses.
   Plant Physiol. Biochem. 121, 153-160, 2017. ISSN: 0981-9428.
   DOI: http://dx.doi.org/10.1016/j.plaphy.2017.10.022
   IF: 2.718

Magyar nyelvű konferencia közlemények (1)

6. **Pesti-Asbóth, G.**, Novotniné Dankó, G., Győri, Z., Balogh, P., Gálné Remenyik, J.: Folyékony tejpótló kiegészítés hatása szopós malacok szénhidrát anyagcseréjét szabályozó hormonokra.
   In: XXXVI. Óvári Tudományos Nap - Hagyomány és innováció az agrár- és élelmiszergazdaságban: Tudományos Nap Összefoglalók. Szerk.: Bali Papp Ágnes, Szalka Éva, Széchenyi István Egyetem Mezőgazdaság- és Élelmiszertudományi Kar, Mosonmagyaróvár, 276-283, 2016. ISBN: 9786155391798

Magyar nyelvű absztrakt kiadványok (1)

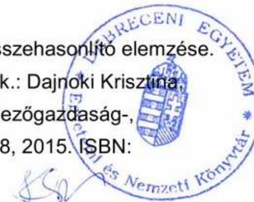
7. **Pesti-Asbóth, G.**, Szilágyi, E., Szilágyi-Tolnai, E., Oláh, J., Stündl, L., Gálné Remenyik, J.: Takarmány-adalékanyag hatása brojler csirke szénhidrát anyagcseréjére.
   In: Tavaszi Szél Konferencia 2019 : Nemzetközi Multidiszciplináris Konferencia : Absztraktkötet. Szerk.: Németh Katalin, Doktoranduszok Országos Szövetsége, Debrecen, 78-79, 2019. ISBN: 9786155586422

További közlemények

Magyar nyelvű könyvrészletek (2)

8. Biró, A., Homoki, J., **Pesti-Asbóth, G.**, Horváth, B., Cziáky, Z., Máthé, E., Gálné Remenyik, J.: Természetes eredetű antioxidánsok.
   In: A fizioterápia dilemmái. Szerk.: Sandra Sándor, San-Ergonómia Kft., Budapest, 177-217, 2017. ISBN: 9786158081603

9. **Pesti-Asbóth, G.**: A magyarországi meggyfajták melatonin tartalmának összehasonlító elemzése.
   In: Interdiszciplináris tudományos konferencia : tanulmánykötet. Szerk.: Dajnoki Krisztina, Szőllősi László, Debreceni Egyetem Gazdaságtudományi Kar és a Mezőgazdaság-, Élelmiszertudományi és Környezetgazdálkodási Kar, Debrecen, 83-88, 2015. ISBN: 9789634737698



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Idegen nyelvű, külföldi könyvrészletek (1)

10. Gálné Remenyik, J., Forgács, I. N., **Pesti-Asbóth, G.**, Gál, F., Csötönyi, O., Babinszky, L., Halas, V.: Occurrence of Hyperhomocysteinemia in Broilers and Reduction of Its Harmful Effects with Betaine- and Berberine-Supplemented Diets.
    In: Feed Additives - Recent Trends in Animal Nutrition, InTechOpen, Rijeka, 1-29, 2024.
    ISBN: 9781837690824

Magyar nyelvű tudományos közlemények hazai folyóiratban (2)

11. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: A hőstressz káros hatása a brojler antioxidáns státuszára és ezen hatás csökkentése takarmányozással: I. rész A hőstressz és az antioxidáns védelmi rendszer.
    Magy. Allatorv. Lapja. 138, 471-481, 2016. ISSN: 0025-004X.
    IF: 0.189

12. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: A hőstressz káros hatása a brojler antioxidáns státuszára és ezen hatás csökkentése takarmányozással: II. rész A hőstressz csökkentése takarmányozási módszerekkel.
    Magy. Allatorv. Lapja. 138, 559-564, 2016. ISSN: 0025-004X.
    IF: 0.189

Idegen nyelvű tudományos közlemények hazai folyóiratban (1)

13. Csernus, B., Biró, S., Babinszky, L., Stündl, L., Gálné Remenyik, J., **Pesti-Asbóth, G.**, Oláh, J., Czeglédi, L.: The effect of β-glucan, carotenoids, oligosaccharides and anthocyanins on bacteria groups of excreta in broiler chickens.
    Acta agraria Debreceniensis. 1, 15-20, 2022. ISSN: 1587-1282.
    DOI: http://dx.doi.org/10.34101/ACTAAGRAR/1/10639

Idegen nyelvű tudományos közlemények külföldi folyóiratban (9)

14. Szőke, Z., Fauszt, P., Mikolás, M., Dávid, P., Szilágyi-Tolnai, E., **Pesti-Asbóth, G.**, Homoki, J., Forgács, I. N., Gál, F., Stündl, L., Czeglédi, L., Stágel, A., Biró, S., Gálné Remenyik, J., Paholcsek, M.: Comprehensive analysis of antimicrobial resistance dynamics among broiler and duck intensive production systems.
    Sci Rep. 15 (1), 1-23, 2025. EISSN: 2045-2322.
    DOI: http://dx.doi.org/10.1038/s41598-025-89432-z
    IF: 3.8 (2023)

DEBRECENI EGYETEM
Egyetemi és Nemzeti Könyvtár

15. Csernus, B., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Biró, S., Babinszky, L., Stündl, L., Oláh, J., Vass, N., Czeglédi, L.: Impact of Selected Natural Bioactive Substances on Immune Response and Tight Junction Proteins in Broiler Chickens.
    Veterinary Medicine and Science. 11 (2), 1-11, 2025. ISSN: 2053-1095.
    DOI: http://dx.doi.org/10.1002/vms3.70175
    IF: 1.8 (2023)

16. Gál, K., **Pesti-Asbóth, G.**, Vass, M., Biró, A., Markovics, A., Homoki, J., Fidler, G., Paholcsek, M., Cziáky, Z., Németh, N., Gálné Remenyik, J., Soltész, P.: Monitoring and recovery of hyperglycaemia-induced endothelial dysfunction with rheopheresis in diabetic lower extremity ulceration with hyperviscosity.
Diabetes and Vascular Disease Research. 19 (6), 1-14, 2022. ISSN: 1479-1641.
DOI: http://dx.doi.org/10.1177/14791641221131788
IF: 2.4

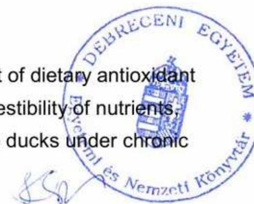
17. Molnár, Á., Homoki, D., Bársony, P., Kertész, A., Gálné Remenyik, J., **Pesti-Asbóth, G.**, Fehér, M.: The Effects of Contrast between Dark- and Light-Coloured Tanks on the Growth Performance and Antioxidant Parameters of Juvenile European Perch (Perca fluviatilis).
Water. 14 (6), 1-10, 2022. EISSN: 2073-4441.
DOI: http://dx.doi.org/10.3390/w14060969
IF: 3.4

18. Fehér, M., Fauszt, P., Szilágyi-Tolnai, E., Fidler, G., **Pesti-Asbóth, G.**, Stágel, A., Szűcs, I., Biró, S., Gálné Remenyik, J., Paholcsek, M., Stündl, L.: Effects of phytonutrient-supplemented diets on the intestinal microbiota of Cyprinus carpio.
PLoS One. 16 (4), 1-24, 2021. EISSN: 1932-6203.
DOI: http://dx.doi.org/10.1371/journal.pone.0248537
IF: 3.752

19. Szilágyi-Tolnai, E., Fauszt, P., Fidler, G., **Pesti-Asbóth, G.**, Szilágyi, E., Stágel, A., Kónya, J., Szabó, J., Stündl, L., Babinszky, L., Gálné Remenyik, J., Biró, S., Paholcsek, M.: Nutraceuticals Induced Changes in the Broiler Gastrointestinal Tract Microbiota.
mSystems. 6 (2), 1-25, 2021. EISSN: 2379-5077.
DOI: https://doi.org/10.1128/mSystems.01124-20
IF: 7.324

20. Csernus, B., Biró, S., Babinszky, L., Komlósi, I., Jávor, A., Stündl, L., Gálné Remenyik, J., Bai, P., Oláh, J., **Pesti-Asbóth, G.**, Czeglédi, L.: Effect of Carotenoids, Oligosaccharides and Anthocyanins on Growth Performance, Immunological Parameters and Intestinal Morphology in Broiler Chickens Challenged with Escherichia coli Lipopolysaccharide.
Animals (Basel). 10 (2), 1-20, 2020. ISSN: 2076-2615.
DOI: http://dx.doi.org/10.3390/ani10020347
IF: 2.752

21. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: Effect of dietary antioxidant supplementations on antioxidant parameters, rectal temperature, digestibility of nutrients, performance and chemical composition of meat in Cherry Valley type ducks under chronic heat stress.
Europ. Poult. Sci. 84, 1-15, 2020. ISSN: 1612-9199.
DOI: http://dx.doi.org/10.1399/eps.2020.306
IF: 0.84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22. Szabó, K., Gesztelyi, R., Lampé, N., Kiss, R., Gálné Remenyik, J., **Pesti-Asbóth, G.**, Priksz, D., Szilvássy, Z., Juhász, B.: Fenugreek (Trigonella Foenum-Graecum) Seed Flour and Diosgenin Preserve Endothelium-Dependent Arterial Relaxation in a Rat Model of Early-Stage Metabolic Syndrome.
Int. J. Mol. Sci. 19 (3), 1-21, 2018. ISSN: 1661-6596.
DOI: http://dx.doi.org/10.3390/ijms19030798
IF: 4.183

Magyar nyelvű konferencia közlemények (1)

23. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: Mikrobiális fermentációs eljárással előállított új probiotikum felhasználásának lehetősége a brojler takarmányozásban.
In: Tavaszi szél 2018 : Tanulmánykötet. Szerk.: Szabó Csaba, Doktoranduszok Országos Szövetsége, Budapest, 44-53, 2018. ISBN: 9786155586316

Magyar nyelvű absztrakt kiadványok (3)

24. Jevcsák, S., **Pesti-Asbóth, G.**, Bíróné Molnár, P., Gálné Remenyik, J., Murányi, E., Sipos, P.: Egyes gabonafélék rezisztens keményítő tartalmának vizsgálata.
In: Magyar Táplálkozástudományi Társaság XLIII. Vándorgyűlése Program Füzet és az Előadások Összefoglalói. Szerk.: Biró Lajos, Gelencsér Éva, Lugasi Andrea, Rurik Imre, Magyar Táplálkozástudományi Társaság elnöke, Budapest, 30, 2018. ISBN: 97861556060609

25. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: Egy új mikrobiális fermentációs eljárással előállított probiotikum felhasználásának lehetősége a brojler takarmányozásban.
In: Tavaszi szél konferencia 2018 Nemzetközi multidiszciplináris konferencia : Abszrtraktkötet. Szerk.: Keresztes Gábor, Doktoranduszok Országos Szövetsége, Budapest, 53-54, 2018. ISBN: 9786155586262

26. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: A tartós hő-stressz káros hatásának csökkentése takarmányozási módszerekkel a pecsenyekacsa tartásban.
In: XXXVI. Óvári Tudományos Nap - Hagyomány és innováció az agrár- és élelmiszergazdaságban: Tudományos Nap Összefoglalók. Szerk.: Bali Papp Ágnes, Szalka Éva, Széchenyi István Egyetem Mezőgazdaság- és Élelmiszertudományi Kar, Mosonmagyaróvár, 264, 2016. ISBN: 9786155391798

Idegen nyelvű absztrakt kiadványok (4)

27. Dobránszki, J., Hidvégi, N., Gulyás, A., **Pesti-Asbóth, G.**, Bíróné Molnár, P., Forgács, I. N., Gálné Remenyik, J.: Ultrasound enhances plant growth and development by altering the DNA methylation, mRNA transcription and hormonal balance.
In: Biotechnology at the University of Debrecen - 2022 International Symposium : Abstract Book, Debreceni Egyetem, Printart-Press Kft., Debrecen, 20, 2022. ISBN: 9789634904687

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28. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: Effects of chronic heat stress on performance of meat type ducks.
In: Krmiva 2018 : Book of abstracts of the 25th International Conference. Ed.: Mario Modric, [s.n.], Zagreb, 39, 2018.

29. Jevcsák, S., **Pesti-Asbóth, G.**, Bíróné Molnár, P., Gálné Remenyik, J., Murányi, E., Diósi, G., Sipos, P.: Total starch content and properties of two proso millet (Panicum miliaceum L.) varieties.
In: 9th Central European Congress on Food (CEFood). Food Science for Well-being. Ed.: L. Gaceu, M. Mironescu, G. Mohan, Lucian Blaga University of Sibiu Press, Sibiu, 139, 2018.
ISBN: 9786061215461

30. Horváth, M., **Pesti-Asbóth, G.**, Gálné Remenyik, J., Babinszky, L.: Impact of chronic heat stress on digestibility of nutrients, performance, and antioxidant capacity of meat type ducks.
In: 2nd World Conference on Innovative Animal Nutrition and Feeding Abstract Book, AKCongress, Budapest, 61-62, 2017.

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A közlő folyóiratok összesített impakt faktora (az értekezés alapjául szolgáló közleményekre): 13,494

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