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Stress as a factor modifying the metabolism in poultry. A review

Stres jako czynnik modyfikujący przemiany metaboliczne u drobiu.
Praca przeglądowa

Summary. This article presents the influence of different stress factors on hormone, sugar, lipid and protein metabolism in poultry. Based on the literature, the main physiological stress indicators in poultry were distinguished. It was stated that investigations on the stress should be continued, including searching for good methods of stress control strategy, because the success in poultry breeding consists in keeping the stress at the optimal level rather than in its elimination.

Key words: poultry, stress, metabolism

INTRODUCTION

A typical trait of live organisms is their capability for maintaining their physiological and biochemical characteristics at a stable level. All factors that disturb this stability (homeostasis) are referred to as stressors, and response to them is referred to as stress [Pawlak and Kontecka 1995]. In the course of industrial, large-flock breeding, birds are exposed to a number of stress factors. Depending on the character and intensity of a stressor, stress may exert a positive effect by evoking intensified adaptation and increasing general immunity of the body. Nonetheless, the extent of metabolic transformations and their consequences are determined by the type, extensiveness and duration of stress. Too intensified and long-lasting stress induces disorders of a daily rhythm of hormones secretion, physiological and morphological changes, manifested mainly in changes of blood composition, changes in muscle tissue and formation of meat defects. In a consequence, long-standing exposure to a stress factor elicits deterioration of immunity, decreased production performance, incidence of pathological symptoms, and even death [Fitko *et. al*. 1992a, Siegel 1971, Pijarska *et al*. 2006]. Hence, in poultry production the effective minimization of all stressogenic factors is an element of a successful production process.

EFFECT OF STRESS ON HORMONAL TRANSFORMATIONS

The body's response to stress is elicited by the entire complex neuro-hormonal-humoral transformation involving the action of concomitantly released mediators and modulators of anti-stress reactions, including: natural endorphins, serotonin, histamines, adrenaline, peptide hormones, liberins, prostaglandins and other biologically-active substances [Kania *et al*. 1999]. During the stress reaction, the hypothalamic-pituitary-adrenal axis is being activated (somatic or physiological stress), which results in the secretion of corticoids: corticosterone (in poultry and rodents) or cortisol (in pigs, cattle and dogs) [Siegel 1971, Siegel 1980]. The endocrine mechanism of stress regulation begins from the stimulation of hypothalamus and release of adrenocorticotropic hormone (ACTH) from the anterior pituitary, which enhances the secretion of adrenal cortex steroids. The continuous stimulation of the adrenal cortex leads to the intermittent increase in the level of corticosteroids. They are responsible for the formation of glucose molecules from reserves of carbohydrates, lipids and proteins. Corticosteroids contribute to the development of many diseases related to continuous stress, including diseases of the circulatory and alimentary systems, as well as to hypercholesterolemia or suppression of antibodies production [Siegel 1985]. In turn, in the case of strong psychogenic or emotional stress, the sympathetic-spinal-adrenal axis is being activated, which results in the release of catecholamines from adrenal medulla (adrenaline and noradrenaline). In the case of birds, catecholamines evoke a reaction referred to as "fight or flight" and induce immediate secretion of glucose to blood, degradation of glycogen accumulated in liver, stimulation of the activity of vasomotoric center, changes in the intensity of ventilation, and increased nervous sensitivity [Siegel 1980]. In addition, catecholamines stimulate the activity of hepatic adenyl- cyclase. The cAMP enzyme is responsible for the regulation of many chemical reactions in physiological processes requiring energy, and stimulates directly the synthesis of antibodies [Brown and Nestor 1973]. As claimed by many authors, a reliable indicator in the evaluation of birds susceptibility to various stressors, e.g. transport, temperature changes and crowding, is the blood level of corticosterone [Davis and Siopes 1989, Fitko *et al.* 1992a, Fitko *et al*. 1992b].

An increased level of corticosterone in blood of chickens in stress immobilization was noted by Wiśniewski *et al.* [1989] and Fitko *et al*. [1992c]. In turn, an increased blood level of corticosterone in turkeys was recorded by Wójcik *et al*. [2001]. Experiments conducted by Ognik [2007] and Truchliński *et al*. [2007], where short-term stress was applied in the form of a combination of various factors (crowding, temperature and light changes), also demonstrated an increased level of this stress hormone in blood plasma of turkey hens. There are also some reports showing that, apart from affecting the secretion of adrenal hormones, the stress factors may as well influence the functioning of other endocrine glands [Friedrich 1992, Sahin *et. al*. 2003, Scanes 2009]. Some works indicate that pancreatic alpha cells stimulated in response to stress in both the mammals and in birds are responsible for the secretion of glucagon [Freeman 1987]. In a study with chickens, Bowen and Washburn [1984] noted suppressed secretion of thyroid gland hormones, i.e. T3 (triiodothyronine) and T4 (thyroxine), under stress conditions of increased temperature. In turn, Deyhim and Teeter [1991] observed a decreased level of T3 accompanied by an increased level of T4 in chickens under the influence of increased temperature of air. An opposite dependency between the temperature of birds environment and plasma level of triiodothyronine is a commonly known fact. Triiodothyronine and thyroxine serve an important function in thermoregulation in birds, whereas the plasma level of T3 is positively correlated with heat production [Eid *et al*. 2003, Iqbal *et al*. 1990, May *et al*. 1986]. Various stress factors may also elicit an increase in: thyroliberin (thyrotropin-releasing hormone, TSH-RH), thyreotropin (thyroid-stimulating hormone, TSH), triiodothyronine (T-3), thyroxine (T-4), opioids, serotonin and dopamine, as well as a decrease in: gonadoliberin (GnRH) and gonadotropins (luteotropin-LH and folliculotropin-FSH), gonad hormones – testosterone, estrogens and progesterone, and growth hormone (GH) [Iqbal *et. al*. 1990]. A research by Bruggeman *et al.* [1998] confirms the suppression of growth hormone secretion in chickens under stress induced by food restriction.

EFFECT OF STRESS ON CARBOHYDRATE METABOLISM

To enable a rapid response of an animal to detrimental environment changes, all defense mechanisms are being mobilized, and energetic reserves of heart, liver and even muscles are being utilized. Released are substances that are easily available to the organism that will allow it to absorb energy indispensable in the fight for survival of a stress situation. At stress, the demand for energy increases even several times and the preferred energetic substrate is glucose. Hence, a temporary increase in blood level of glucose (hyperglycemia) has been observed by researchers. There are different mechanisms responsible for the induction of hyperglycemia. One of them is the stimulation of the sympathetic-spinal-adrenal axis manifested in an increased level of adrenaline which, in turn, stimulates hepatic glycogenolysis and causes suppression of insulin secretion [Krasnodębska-Depta and Koncicki 2002]. Hyperglycemia may be induced by the action of glycocorticoids secreted by the adrenal cortex [Fitko and Kądziołka 1994]. An increased glucose level in chickens was also observed during ACTH-induced stress [Latour *et al*. 1997, Puvadolpirod and Thaxton 2000]. In addition, the increased glucose level in blood of chickens correlated with an increased level or corticosterone and a lack of appetite was reported by Honda *et al*. [2007]. These authors explain that the corticotrophin-releasing hormone (CRF), increasing plasma level of corticosterone, plays a significant role as a mediator of many proteins inhibiting the satiety centre in the central nervous system. As demonstrated by investigations of Pijarska *et al*. [2006], Ondrasovicova *et al*. [2008] and Warris *et al.* [1997], some stress factors related with low-frequency vibrations (e.g. during road transport) may, in turn, trigger a decrease in blood level of glucose. The above authors explain this phenomenon by depletion of energetic reserves, e.g. of hepatic glycogen, which may be due to inaccessibility of feed during long-lasting transport. Nevertheless, the stress reaction to the duration of transport is also depend on poultry species. In turn, when conducting studies with different poultry species, Rajman *et al*. [2006], Yaman *et al*. [2000] and Jong *et al*. [2003] established that the level of glucose in birds was not subject to significant fluctuations during starvation stress. According to those authors, the likely reason of this fact are biochemical mechanisms that precisely regulate glucose level in order to maintain homeostasis. An interesting phenomenon of modification of carbohydrate metabolism during stress is the so-called insulin resistance, i.e. a lack of tissues susceptibility (tissues of liver, muscles and fat tissue) to insulin, even that of exogenous origin. The resistance of tissues to insulin action is not due to a decrease in its activity but to the so-called metabolic block. The exact cause of this phenomenon remains unknown, it is only known that it occurs at the level of cell membrane and consists in the impairment of the activities of the second or secondary chemical signal which affects anabolic enzymes [Kocić *et al*. 2007].

EFFECT OF STRESS ON LIPID METABOLISM

Disorders of lipid metabolism in birds are, to a large extent, determined by the type of stressors the birds are exposed to. As it results from literature findings, changes in particular lipid indices are also affected by poultry species. A research by Krasnodębska-Depta and Koncicki [2002] conducted with turkeys demonstrates that heat stress elicited a significant increase in blood level of triacyloglycerides, whereas the concentration of total cholesterol was remaining at a relatively stable level. In contrast, chickens exposed to varying temperatures were characterized by large fluctuations in lipid metabolism indices [Nawalany *et al.* 2010]. The elevated temperature resulted in increased levels of cholesterol and total lipids, whereas a decrease in temperature caused a diminished level of this parameter and of free fatty acids contents. Both the lower and higher temperature of the environment, compared to the optimal temperature, affected a decrease in blood level of total lipids. The increased blood levels of total cholesterol and triacyloglycerides were determined in a study with chickens, laying hens and common quail, in which stress was induced as a result of increasing environment temperature [Sahin *et al.* 2006]. In contrast, a decrease in total cholesterol level under the influence of transport stress was reported in turkeys by Keller [1990] and Kowalski *et al*. [2001]. In turn, as indicated in a study of Rajman *et al.* [2006], the starvation of chickens resulted in decreased levels of all lipid indices, i.e. total lipids, cholesterol, HDL cholesterol fraction, and triacyloglycerides. On the contrary, neither cholesterol nor its fractions were observed to diminish in starved chickens in a research by Yaman *et al.* [2000]. The decreased level of triacyloglycerides in the state of starving is due to the fact that the body is forced to absorb energy from lipids constituting the storage adipose tissue. As a result of metabolism shifting into triglycerides degradation, high quantities of free fatty acids are appearing in blood. Part of them are released directly by tissues, whilst most of them are utilized by liver which transforms them into ketone bodies. Already in this form, they are consumed by tissues as energy. A rapid increase in the level of free fatty acids occurs also at deficiency of insulin which inhibits their synthesis. The stress-induced changes in other lipid indices may as well be explained by the suppressed secretion of this hormone. For insulin is a very strong inhibitor of lipolysis, and its deficiency results in the enhanced activity of lipolytic enzymes. The process of lipolysis is additionally stimulated by corticoids released under the state of stress. In their study with chickens, Eid *et al.* [2003] established that under the influence of corticosterone administration the concentration of triacyloglycerides in blood plasma was increasing to a significant extent. The model, ACTH administration-induced stress in chickens caused changes that involved increased levels of triglycerides, total cholesterol as well as its HDL and LDL fractions [Latour *et al.* 1997*,* Puvadolpirod and Thaxton 2000]. While discussing the impact of stress on lipid metabolism, its effect on peroxidation process of lipids and lipoproteins cannot be neglected. As shown by ample investigations, the environmental stress – heat stress in particular – induces the so-called oxidative stress characterized by the preponderance of oxidation processes over reduction processes. The condition of oxidative stress results in the enhanced production of reactive oxygen species that induce lipid peroxidation reactions, which are in turn manifested by an increased level of, i.a., malondialdehyde (MDA) in plasma and tissues [Sahin *et al.* 2002]. A research by Klandorf *et al.* [2004] demonstrated that compared to mammals, birds possess a more efficient antioxidative system, which is probably ascribed to uric acid being – in the case of birds – the end product of protein catabolism and simultaneously a strong antioxidant. It does not mean, however, that the oxidative stress occurs only in the mammals. As indicated by ample investigations, it is also observed in birds, especially those exposed to high temperatures [Lin *et al.* 2006*,* Mahmoud *et al.* 2003*,* Sahin *et al.* 2003]. Induction of lipids peroxidation was noted in chickens exposed to corticosterone-induced stress, especially at the long-lasting exposure [Lin *et al.* 2004a*,* Lin *et al.* 2004b]. In addition, authors of those works reported simultaneously an increase in levels of enzymatic and non-enzymatic antioxidants, i.e. uric acid and ceruloplasmin, which pointed to the activation of antioxidative defense mechanisms under stress conditions.

EFFECT OF STRESS ON PROTEIN METABOLISM

An increase in the quantity of corticoids circulating in blood occurring under stress conditions is the cause of suppressed synthesis of body proteins and enhanced proteolysis, because these hormones exert mainly catabolic effects. Degradation of proteins is supposed to provide the availability of amino acids, as gluconeogenic substrates, for glucose synthesis. One of these substrates is glycerol being a product of lipids degradation, however it covers for only 20% of glucose demand. The other substrates are, therefore, products of proteins degradation. Initially, it has been speculated that it does not refer to tissue proteins of heart and lungs, however it appears that all tissues, except for the nervous system, are subject to enhanced catabolic transformations proportionally to the level and quantitative composition of protein. It is especially tangible in the muscle tissue that contains most of the body nitrogen. This results in a decrease of muscle mass, and in the case of young organisms also in growth retardation. Such tendencies were observed in chickens exposed to stress induced by corticosterone administration [Hayashi *et al*. 2002]. Similar effects were also reported during feed deprivation [Kita, 1996*,* Rajman *et al.* 2006]. According to those authors, the starved chickens were characterized by ca. 2-fold decrease in hepatic synthesis of protein. Diminished plasma levels of total protein and albumins were determined by Yaman *et al*. [2000]. The decreased plasma level of total protein was observed by Krasnodębska-Depta and Koncicki [2002] in turkeys exposed to high temperature, however it was short-lasting. According to those authors, it could have been due to hypotonic overhydration induced by excessive water intake.

Table.1. Pathological states occurring in the body poultry under the influence of stress
Tabela 1. Stany patologiczne, jakie zachodzą w organizmie ptaków pod wpływem stresu

Trait Cecha	Indicator Wskaźnik	References Piśmiennictwo
Changes in anatomical constitution of organs and tissues Zmiany w budowie anatomicznej narządów i tkanek	atrophy of thymus and atrophy of the bursa of Fabricius in young birds – zanik grasicy oraz zanik torebki Fabry-cjusza u młodych ptaków dilation of anterior pituitary and adrenal glands rozszerzenie przedniego płata przysadki mózgowej i gruczołów nadnerczy diminished increase and enhanced atrophy of muscle mass zmniejszony wzrost i zwiększony zanik masy mięśniowej disorders in the growth of cartilage and bones zaburzenia wzrostu chrząstki i kości excess of fatty tissue in abdominal cavity nadmiar tkanki tłuszczowej w jamie brzusznej ascites – wodobrzusze	Brown 1973, Freeman 1980, Freeman 1987
Changes in the morphological and biochemical picture of blood Zmiany w obrazie morfologicznym i biochemicznym krwi	increased concentrations of corticosterone, insulin or glucagon wzrost stężenia kortykosteronu, insuliny lub glukagonu changes in glucose concentration (hyperglycemia/ hypo-glycemia) – zmiany stężenia glukozy (hiperglikemia/ hipoglikemia) changes in the concentration of unsaturated fatty acids zmiany stężenia nienasyconych kwasów tłuszczowych changes in the concentration of leucocytes zmiany stężenia leukocytów release of acute phase proteins and cytokines (monokines, lymphokines) – uwalnianie białek ostrej fazy oraz cyto-kin (monokiny, limfokiny) synthesis of specific heat shock protein synteza specyficznych białek szoku termicznego	Friedrich 1992, Kowalski *et al.* 2001, Shini *et al.* 2010
Others Inne	immunosuppression – immunosupresja increased body temperature podwyższona temperatura ciała reduced free feed intake zmniejszone dobrowolne pobieranie paszy	Fitko *et al.* 1992c, Habbak *et al.* 2011, Letheya *et al.* 2003, Siegel 1985

Chickens and turkeys exposed to short-term heat stress were also characterized by a significant increase in creatinine concentration [Krasnodębska-Depta and Koncicki 2002, Friedrich 1992]. The increased level of this parameter indicates enhanced catabolism of muscle proteins. In contrast, the starvation-induced stress had no significant effect on this parameter [Rajman *et al.* 2006]. The content of uric acid, being a protein metabolite, was also observed not to fluctuate significantly during starving-induced stress. In turn, investigations by Friedrich [1992] with chickens and these by Krasnodębska-Depta and Koncicki [2002] with turkeys demonstrated that heat stress had effect on decrease in blood level of this parameter, which could be due to a reduced level of total protein as a result of hypotonic overhydration. Contrarily, Arad *et al.* [2006] observed a significant increase in the level of uric acid in chickens exposed to heat stress. Hence, as suggested in a study conducted by Machin *et al*. [2004] with broiler chickens, the application of high-protein diet during severe exposure to stress factors causes an increase in uric acid (a non-enzymatic antioxidant) in blood plasma, and as a result, mitigates the oxidative stress. The activity of enzymes taking part in protein metabolism (more specifically: of amino acid metabolism) under stress conditions was analyzed in a few works only. Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) are intracellular enzymes occurring in high concentrations in liver, heart and skeletal muscles. Their enhanced activity is of diagnostic significance as it usually indicates damage of these organs. As shown by investigations conducted by Krasnodębska-Depta and Koncicki [2002] and Pijarska *et al.* [2006], no significant differences were observed in ALT activity in blood plasma of birds exposed to stress, the differences referred only to the activity of AST.

In summary, it ought to be concluded that stress may exert a negative impact on physiological processes and pose many health problems owing to dysfunctions of hormonal, respiratory and circulatory systems. It may also result in disturbances of immune processes and antioxidative defense as well as in changes of the anatomical constitution of organs and tissues (tab. 1). Despite many achievements in research addressing the effect of stress on metabolic transformations in animals, the knowledge in this respect is still negligible and fragmentary both from the medical, academic and scientific perspective. Therefore, investigations on stress should be continued and focus on the search for effective methods of stress control strategies, because in view of production effectiveness a success in poultry breeding does not mean stress elimination but keeping it at an optimal level.

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Streszczenie. Artykuł przedstawia wpływ różnych czynników stresowych na kształtowanie się przemian hormonalnych, węglowodanowych, lipidowych i białkowych u drobiu. Na podstawie przeanalizowanej literatury wyodrębniono najważniejsze fizjologiczne wskaźniki stresu u drobiu. Stwierdzono, że w dalszym ciągu należy podejmować badania nad stresem, uwzględniając przy tym poszukiwanie dobrych metod strategii kontroli stresu, ponieważ sukces w hodowli drobiu polega raczej nie na wyeliminowanie stresu, lecz utrzymaniu go na optymalnym poziomie.

Słowa kluczowe: drób, stres, przemiany metaboliczne