J. Vet. Malaysia (1995) 7(1):1-6

STRESS, IMMUNITY AND DISEASE RESISTANCE IN POULTRY : A REVIEW

I. Zulkifli

Department of Animal Sciences, Faculty of Veterinary Medicine and Animal Science, Universiti Pertanian Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

SUMMARY

Prolonged stress responses cause reallocation of resources at the biological expense of productivity, health and well-being. The catabolic nature of stress response, mainly via corticosteroids mediation, may curtail humoral and cell-mediated immunities. Mechanisms of stress-elicited immunosuppression may include modifications of enzymatic activity, nucleic acid metabolism, and rate of maturation of lymphocytes, interleukin II synthesis, and programmed cell death. There is considerable evidence suggesting bidirectional interactions between the immune and neuroendocrine systems. Studies in both avian and mammalian species indicate that stress can have both beneficial and adverse influences on resistance to infectious and non-infectious diseases. This phenomenon could be attributed to the effects of corticosteroids on either the particular pathology involved or on immunological defense mechanism.

Keywords: Stress, immunity, disease resistance, poultry.

INTRODUCTION

The poultry environment is composed of various interacting factors that may result in stress responses. Climate, social interactions, bird density, nutrition, disease and human-animal interactions are examples of potential factors that may affect homeostasis (Harvey *et al.*, 1984). Intense selection for rapid growth in broilers result in concomitant greater susceptibility to physiological imbalance (Gross and Siegel, 1993). Responses to a hostile stimulus may include physiological, biochemical, immunological, behavioural and anatomical modifications (Siegel, 1980; 1995; Zulkifli and Siegel, 1995a;b). Of major interest to poultry producers are the consequences of those biologically costly changes, which may be deleterious to the birds' productivity, health and well-being.

Studies with laboratory and domestic animals suggest that environmental fluctuations leave an individual vulnerable to neuroendocrine alterations, thereby may hinder immunity and disease defense (Thaxton, 1978; Kelley, 1985; Roth, 1985). However, stress at an optimal level can possess beneficial qualities as demonstrated by disease resistance (Gross and Siegel, 1993; Zulkifli and Siegel, 1995a;b). In this brief review, the interplay among stress, immunocompetence and disease resistance will be elucidated.

PHYSIOLOGICAL RESPONSES TO STRESS

The physiology of stress in poultry has been comprehensively reviewed (e.g. Freeman, 1971; 1976; 1985; Siegel, 1971; 1980; 1983; 1995; Harvey *et al.*, 1984). Thus, it will only be discussed briefly here. The nervous and endocrine systems play pivotal roles in the response to stressor(s). External and internal stimuli are channelled via the nervous system to the hypothalamus. Regardless the stimulus is perceived as threatening or not, two distinct pathways involving interlocking physiological reactions are activated. The first pathway encompasses of the sympathetic-adrenomedullary (SA) system, which is the basis of Cannon's "flight or fight" mechanism (Freeman, 1971). Although manifestation of the mechanism such as hypertension, increase in muscle tone and nerve sensitivity, polypnoea and hyperglycemia is physiologically dramatic, it is short-term. When the biological system fails to maintain *internal milieu* and behavioural activity is suppressed, the second pathway, the hypothalamic-pituitary-adrenal (HPA) axis is elicited. Sensory inputs cause liberation of corticotrophin-releasing-hormone from the hypothalamus. The neurohormone stimulates the pituitary glands to release adrenocorticotrophic hormone (ACTH) which elicits the adrenal cortex to release glucocorticoids. The main hormone linked with stress in chickens is the steroid, corticosterone (Turner and Bagnara, 1976). Corticosterone travels to all cells in the body and invades the nuclei of the cells (Gross and Siegel, 1993). The result is alteration of production of proteins and enzymes by the cell which leads to signs associated with long-term stress such as cardiovascular diseases, hypercholesteremia, metabolic derangement, reproductive impairment and modifications of immunological activities (Sapolsky, 1992).

IMMUNE RESPONSE

Stress-mediated immunosuppression

The immune system, once considered an autonomous system, is integrated with other physiological systems and is sensitive to regulation of the brain (Ader, 1983). A relatively new discipline, psychoneuroimmunology, has broaden knowledge on the relationship between nervous and immune systems. Although the immune response is affected by the nervous system via direct innervation and/or involvement of the HPA axis (Ballieux and Heijnen, 1987), the effects of HPA axis and corresponding hormones on the immune system appear to be more important. This notion was strengthened by amelioration in the immunosuppressive effects of stress when chickens were given pre-stress treatment with metyrapone, an inhibitor of adrenal steroidogenesis (Thaxton and Siegel, 1973; Gross, 1989). Hence, stress which activates the HPA pathway has a profound impact on the immune system. There is, however, a dearth of information on the relationship between the SA system and immunocompetence in poultry. Studies with mammalian species demonstrated that increased cathecolamines activities suppressed immune functions (Bourne *et al.*, 1974).

Stress influences both cell mediated and antibody dependent immune functions (Ballieux and Heijnen, 1987). Consequences of the direct effect of corticosteroid or indirect effect of ACTH are lymphatic (thymus, spleen and bursa of Fabricius) involution, and reduction and elevation in the number of circulating lymphocytes and polymorphs, respectively (Siegel, 1985). There is considerable information regarding mechanisms involved in the effect of corticosterone on the immune system. *In vitro* studies indicate that corticosteroids bind to specific protein receptors in the cytoplasm of lymphatic cells, and the steroid-receptor complex is transferred to the nucleus. In the nucleus, the complex modifies enzymatic activity, nucleic acid metabolism (Sullivan and Wira, 1979) and production of interleukin II (lymphoid activator) by the T helper cells (Gillis *et al.*, 1979). In mammalian system, delay in maturation of lymphocytes and pulling of these cells out of the blood stream attributable to stress steroid have also been reported (Sapolsky, 1992). Corticosteroid-elicited programmed thymocyte death or apoptosis is another possible mechanism of immunosuppression (Cohen and Duke, 1984; Munck and Guyre, 1991). Compton *et al.* (1990a) reported that exogenous dexamethasone resulted in bursal lymphocyte DNA degradation within 2 to 4 h post treatment. Corticosteroid induces synthesis of an endonuclease, thereby resulting fragmentation of DNA and subsequent cell death (Compton *et al.*, 1990b).

Several studies showed that immunosuppression is not always characteristic of stress. Thaxton and Briggs (1972) reported that neither immobilisation nor injection of formaldehyde (both are potent stressors) influenced the immunocompetence of chickens. There are also inconsistencies concerning the effects of thermal stress on the immune system (Morgan *et al.*, 1976; Zulkifli *et al.*, 1994a;b). Subba Rao and Glick (1977) reported that chronic cold exposure was beneficial, rather than deleterious, to immunoresponse in chickens. The phenomenon could be attributed to cold-stress-mediated thyroid hyperactivity, which may have profound immunoregulatory effect (Marsh, 1992).

Immunological response is dynamic and vulnerable to various internal and external stressors. However, the immune system can be further regulated by many factors such as genetics (Gross and Colmano, 1971; Siegel and Gross, 1980; van der Zijpp, 1983), nutrition (Pardue and Thaxton, 1984; O'Sullivan *et al.*, 1991; Dunnington *et al.*, 1994; Liu *et al.*, 1995), antigen concentration (Ubosi *et al.*, 1985) and interactions of specific and nonspecific environmental effects (Siegel, 1985).

Neuroendocrine-immune bilateral interactions

There is a growing body of evidence indicating the possibility of a bilateral relationship between stress and immune responses (Marsh and Scanes, 1994; Siegel, 1995). Besedovsky and his co-workers are among several pioneers to provide evidence for a bilateral link between the nervous and immune systems. Based on a series of experiments, Besedovsky *et al.* (1979) summarised the phenomenon of the two-way relationship of the immune and neuroendocrine systems as; (1) complex bi-directional interactions demonstrable between the endocrine and the immune system during early ontogeny, (2) hormonal changes induced by the immune response itself, (3) changes in the firing rates of neurons in discrete zones of the hypothalamus during the immune response, and (4) diminution in norepinephrine content of the spleen during immune response. Hence, it is strongly suggestive that the immune system is capable of transmitting cues to the nervous system and eventually activating the neuroendocrine axis.

Although information on the actual transmission of signals from lymphatic tissues to the hypothalamus is fragmentary, several postulations have been made. Ballieux and Heijnen (1987) hypothesised that lymphokines which were synthesised by antigen-activated lymphocytes are responsible for the stimulation of the nervous system. Other postulations include immune complexes, pharmacological mediation liberated during ongoing immune response, or transmission of electrical impulses from nerve endings of lymphoid tissues (Besedovsky *et al.*, 1977). Activation of lymphocytes results in synthesis and release of ACTH-like substance that acts directly on the adrenals and elicits release of corticosteroid in both avian (Siegel *et al.*, 1985) and mammalian (Smith *et al.*, 1982) species. Working with hypophysectomised mice, Smith *et al.* (1982) reported that infection with Newcastle disease virus (NDV) showed a time

dependent increase in corticosterone production with peak concentration 8 h post infection. The same workers, based upon the findings that spleen cells from NDV-infected but not from control hypophysectomised mice exhibited positive immunofluorescence with antibody to ACTH, concluded that lymphocytes produced an ACTH-like substance. Earlier, van Wyck (as cited by Smith *et al.*, 1982) reported a marked increase of plasma corticosteroids levels in seven of eight hypophysectomised human patients treated with a bacterial polysaccharide. According to Smith *et al.* (1982), production of neuroendocrine hormone by lymphocytes is regulated by the major histo-compatibility complex.

The preceding discussion suggests a bilateral link between immune response and neuroendocrine pathways. If the proposed bi-directional relationship between the two system exists, how can we relate this phenomenon to vaccination practices as a disease control strategy? It appears conflicting to activate production of antibody by administrating antigen and at the same time, the ongoing immune response itself increases corticosteroids levels which results in suppression of lymphocytic activities. Probably there is a certain threshold where ongoing immune response has negligible effect on the stress response. Thus, antigen concentration and the environment of the host itself could be important factors in determining threshold response.

DISEASE RESISTANCE

Disease defense is intricate and of a multifactorial nature as it involves factors at the host, pathogen and environment levels. The additive effects of environmental insults, management and genetic factors may disrupt homeostasis and eventually give rise to unexpected and dramatic pathological events. In his review, Siegel (1983) attributed increases in chronic infectious and non-infectious diseases to intensification of animal production which may inflict greater infection pressure on a population. There is considerable evidence indicating that response and adaptation to environmental fluctuations can alter mechanisms of disease resistance. In the context of Selye's "General Adaptation Syndrome" (Selye, 1950), stress-related predicaments may emerge when the biological defense has collapsed during the exhaustion stage. In the case of infectious diseases, the longer the stress response persists, the more vulnerable an individual is to pathogens in its environment.

Stressors may impede humoral and cell mediated immunities, thereby increasing susceptibility to viral diseases, tumors, and mycoplasmal infections in chickens (e.g., Gross and Siegel, 1965; Gross and Colmano, 1969; Gross, 1972; Zulkifli *et al.*, 1994a;b). Gross (1989) reported that chemical inhibition of adrenal steroidogenesis enhanced resistance to viral and respiratory infections in chickens. Thus, corticosteroids may play a pivotal role in simultaneously suppressing the immune system and defenses against viral diseases.

Apart from infectious diseases, studies in humans and laboratory animals suggest that stress may act as a potent carcinogenic agent (Selye, 1979). This relationship has been observed as early as 1759 by Sir Richard Guy (as cited by Selye, 1979), who noted that predominantly, breast cancer patients had history of bereavement or grief. Decline in natural killer cell activity, which is critical in cancer resistance, due to physiological and psychological perturbations may have accounted for the phenomenon (Bloom, 1980).

Although response to nocuous stimuli leads to reallocation of resources (Gross and Siegel, 1993), they have both beneficial and adverse influences on disease resistance. Stressed chickens had increased defense against bacterial diseases (Gross, 1962; Gross and Siegel, 1965; 1979; 1982) with exception of *Salmonella worthington* infection (Thaxton *et al.*, 1974). This phenomenon could be attributed to effects of corticosteroids on either the particular pathology involved or on immunological defense mechanisms (Siegel, 1980). The anti-inflammatory action of corticosteroids is useful against bacterial diseases where the major pathology involves local or generalised inflammation. On the contrary, viral infections cause direct invasion of tissue and inflammation is essential to localise the infection.

Another possible explanation for the contradicting effects of stress on disease resistance is associated with the circulating leucocyte components (Siegel, 1980). Stress causes involution of lymphatic tissues (thymus, spleen, and bursa of Fabricius) which reduces the number of circulating lymphocytes and increases the number of polymorphs (Garren and Shaffner, 1954; 1956; Glick, 1967; Siegel, 1980; 1983). Defenses against viral and bacterial infections are mainly lymphocytic and heterophilic, respectively (Gross, 1962). Hence, stress which increases the number of circulating heterophils and reduces the number of circulating lymphocytes may be advantageous for resistance to bacterial diseases, but not viral diseases.

Similarly, stress also appear to be beneficial on diseases of parasitic origin. Gross (1985) reported that defenses against coccidiosis are mainly cell-mediated and sensitisation to cell-mediated immunity may be enhanced under stressful situations. High levels of social stress or corticosterone administration increased resistance to northern fowl mite (*Ornithonyssus sylvarium*) infestation by altering capillary density at the skin surface (Hall *et al.*, 1979) In the case of non-infectious diseases, stressed chickens, based on muscarinic and nicotinic signs, plasma cholinesterase and brain acetylcholinesterase activities were more resistant to organophosphate toxicity (Brown *et al.*, 1986). Studies on *Trichinella spiralis* (Davis and Reed, 1958) and *Trypanosoma brucei* (Ferguson, 1969) in rodents also suggest that there were benefits of stress in enhancing disease resistance.

CONCLUSION

In a state of homeostasis, the finite pool of resources is allocated accordingly for various purposes such as digestion, growth, reproduction and immunity. However, stress is inevitable for an individual or a population. Response to environmental insults demands immediate energy mobilisation. Although such reaction during the acute stage is of paramount importance for survival, prolonged intense physiological response can be damaging as the stressor itself. The catabolic nature of stress response increases energy expenditure and diverts resources at the expense of health and well-being.

From the preceeding discussion, it appears that the relationships between stress, immunity and disease resistance are not as simple as a stressor having a single, uniform, and direct effect. The possibility of bi-directional interactions between the immune and neuroendocrine systems are undoubtedly of great value for further research on stress in animals. Pathological studies in both avian and mammalian species suggest the contradicting effects of stress on resistance to disease. This phenomenon may become critical when drawing the boundaries between hypo- and hyper-stress conditions, both are undesirable to physical and psychological well-being. Thus, by understanding how stress affects an animal's disease resistance, we can better apply disease control strategies and management tools to more effectively circumvent stress-related diseases and ultimately improvement of livestock well-being and welfare.

REFERENCES

Ader, R. (1983). Developmental psychoneuroimmunology. *Develop. Psychobiol.*, **16:** 251-267.

Ballieux, R.E. and Heijnen, C.J. (1987). Stress and the immune system. *In:* Biology of Stress in Farm Animals. Wiepkema, P.R. and van Adrichem, P.W.M. (Eds.), Martinus Nijhoff Publ., Dordrecht, The Netherlands. pp 29-38.

Besedovsky, H.O., Sorkin, E., Felix, D. and Haas, H. (1977). Hypothalamic changes during the immune response. *Euro. J. Immunol.*, **7:** 323-325.

Besedovsky, H.O., Del Rey, A., Sorkin, E., Da Prada, M. and Keller, H.H. (1979). Immunoregulation mediated by the sympathetic nervous system. *Cell. Immunol.* **48:** 346-355.

Bloom, B.R. (1980). Interferons and the immune system. *Nature*, **284**: 593-595.

Brown, C.W., Gross, W.B. and Ehrich, M. (1986). Effects of social stress on the toxicity of malathion in young chickens. *Avian Dis.*, **30**: 679-682.

Bourne, H.R., Kitchtenstein, L.M., Melmon, K.L., Henny, C.S., Weinstein, Y. and Shearer, G.M. (1974). Modulation of inflammation and immunity by cyclic AMP. *Science*, **184**: 19-28.

Cohen, J.J. and Duke, R.C. (1984). Glucocorticoid activation of a calcium dependent endonuclease in thymocyte nuclei leads to cell death. *J. Immunol.*, **132**: 38-42.

Compton, M.M., Gibbs, P.S. and Johnson, L.R. (1990a). Glucocorticoid activation of deoxyribonucleic acid degradation in bursal lymphocytes. *Poultry Sci.*, **69**: 1292-1298.

Compton, M.M., Gibbs, P.S. and Swicegood, L.R. (1990b). Glucocorticoid mediated activation of DNA degradation in avian lymphocytes. *Gen. Comp. Endocrinol.*, **80**: 68-79.

Davis, D.E. and Reed, C.P. (1958). Effect of behaviour on development of resistance on trichinosis. *Proc. Soc. Exp. Biol. Med.*, **99**: 269-272.

Dunnington, E.A., Zulkifli, I., Siadak, D, Larsen, A.S. and Siegel, P.B. (1994). Dietary methionine and antibody response in broiler cockerels. *Arch. Geflugelk.*, **58**: 124-129

Ferguson, W. (1969). The role social stress in epidemiology. *Br. Vet. J.*, **125**: 253-254.

Freeman, B.M. (1971). Stress and domestic fowl: a physiological appraisal. *World's Poult. Sci. J.*, **27**: 263-275.

Freeman, B.M. (1976). Stress and domestic fowl: a physiological re-appraisal. *World's Poult. Sci. J.*, **32**: 249-256.

Freeman, B.M. (1985). Stress and domestic fowl: Physiological fact or fantasy?. *World's Poult. Sci. J.*, **41**: 45-50.

Garren, H.W. and Shaffner, C.S. (1954). Factors concerned in the response of young New Hampshires to muscular fatigue. *Poultry Sci.*, **33**: 1095-1104.

Garren, H.W. and Shaffner, C.S. (1956). How the period of exposure to different stress stimuli affects the endocrine and lymphatic gland weight of young chickens. *Poultry Sci.*, **35**: 266-272.

Gillis, S., Crabtree, G.R and Smith, K.A. (1979). Glucocorticoid-induced inhibition of T-cell growth factor production. 1. The effects of mitogen-induced lymphocyte proliferation. *J. Immunol.*, **123**: 1624-1631.

Glick, B. (1967). Antibody and gland studies in cortisone and ACTH-injected birds. *J. Immunol.*, **98**: 1076-1084.

Gross, W.B. (1962). Blood culture, blood counts, and temperature records in an experimentally produced "air sac disease" and uncomplicated *Escherichia coli* infection of chickens. *Poultry Sci.*, **41**: 691-700.

Gross, W.B. (1972). Effect of social stress on occurrence of Marek's disease. *Am. J. Vet. Res.*, **33**: 2275-2279.

Gross, W.B. (1985). Effects of social environment and oocyst dose on resistance and immunity to *Eimeria tenella* challenge. *Avian Dis.*, **29**: 1018-1029.

Gross, W.B. (1989). Effect of adrenal blocking chemicals on viral and respiratory infections in chickens. *Can. J. Vet. Res.*, **53**: 48-51.

Gross, W.B. and Colmano, G. (1969). Effect of social isolation on resistance to some infectious agents. *Poultry Sci.*, **48**: 514-520.

Gross, W.B. and Colmano, G. (1971). Effects of infectious agents on chickens selected for plasma corticosterone response to social stress. *Poultry Sci.*, **50**: 1213-1217.

Gross, W.B. and Siegel, H.S. (1965). The effect of social stress on resistance to infection with *Escherichia coli* or *Mycoplasma gallisepticum*. *Poultry Sci.*, **44**: 998-1001.

Gross, W.B. and Siegel, P.B. (1979). Adaptation of chickens to their handler and the experimental results. *Avian Dis.*, **23**: 708-714.

Gross, W.B. and Siegel, P.B. (1982). Influences of sequences of environmental factors on the response of chickens to fasting and to *Staphylococccus aureus* infection. *Am. J. Vet. Res.*, **43:** 137-139.

Gross, W.B. and Siegel, P.B. (1993). General principles of stress and welfare. *In*: Livestock Handling and Transport. Grandin, T. (Ed.), CAB International, Wollingford, U.K. pp 21-34.

Hall, R.D., Gross, W.B. and Turner, E.C., Jr. (1979). Population development of *Ornithonyssus sylvarium* (canastrini and fazango) on Leghorn roosters inoculated with steroids and subjected to extremes of social interaction. *Vet. Parasit.*, **5**: 287-297.

Harvey, S., Phillips, J.G., Rees, A. and Hall, T.R. (1984). Stress and adrenal function. *J. Expt. Zool.*, **232**: 633-645.

Kelley, K.W. (1985). Immunological consequences of changing environmental stimuli. *In:* Animal Stress. Moberg, G.P. (Ed.), Waverly Press, Inc., Baltimore, MD. pp 193-223.

Liu, G., Dunnington, E.A. and Siegel, P.B. (1995). Growth related traits in body weight selected lines and their crosses reared under different nutritional regimens. *Br. Poult. Sci.* **36**: 209-219.

Marsh, J.A. (1992). Neuroendocrine-immune interactions in the avian species-A review. *Poult. Sci. Rev.*, **4**: 129-167.

Marsh, J.A. and Scanes, C.G., 1994. Neuroendocrine-immune interactions. *Poultry Sci.*, **73**: 1049-1061.

Morgan, G.W., Thaxton, P. and Edens, F.W. (1976). Reduced symptoms of anaphylaxis in chickens by ACTH and heat. *Poultry Sci.*, **55**: 1498-1504.

Munck, A. and Guyre, P.M. (1991). Glucorticoids and immune function. *In:* Psychoneuroimmunology. Ader, R., Felten, D.L. and Cohen, N. (Eds.), Academic Press Inc., San Diego, CA. pp 447-493.

O'Sullivan, N.P., Dunnington, E.A., Smith, E.J., Gross, W.B. and Siegel, P.B. (1991). Performance of early and late feathering broiler breeder females with different feeding regimes. *Br. Poult. Sci.*, **32**: 981-995.

Pardue, S.L. and Thaxton, P. (1984). Evidence of amelioration of stress-mediated immunosuppression by ascorbic acid. *Poultry Sci.*, **63**: 1262-1268.

Roth, J.A. (1985). Cortisol as mediator of stress-associated immunosuppression in cattle. *In:* Animal Stress. Moberg, G.P. (Ed.), Waverly Press, Inc., Baltimore, MD. pp 225-243.

Sapolsky, R.M. (1992). Neuroendocrinology of the stress response. *In:* Behavioral Endocrinology. Becker, J.B., Breedlove, S.M. and Crews, D. (Eds.), MIT Press, Cambridge, MA. pp 287-324.

Selye, H. (1950). The Physiology and Pathology of Exposure to Stress. Acta Inc., Montreal, Canada.

Selye, H. (1979). Stress, cancer, and the mind. *In:* Cancer, Stress and Death. Taché, J., Selye, H. and Day, S.B. (Eds.), Plenum Publ. Copr. New York, NY. pp 11-19.

Siegel, H.S. (1980). Physiological stress in birds. *Bioscience*, **30**: 529-534.

Siegel, H.S. (1983). Effects of intensive production methods on livestock health. *Agro-Ecosystem*, **8**: 215-230.

Siegel, H.S. (1985). Immunological responses as indicator of of stress. *World's Poult. Sci. J.*, **41**: 36-44.

Siegel, H.S. (1995). Stress, strains and resistance. *Br. Poult. Sci.*, **36**: 3-22.

Siegel, H.S., Gould, N.R. and Latimer, J.W. (1985). Splenic leukocytes form chickens injected with *Salmonella pullorum* antigen stimulate production of corticosteroids by isolated adrenal cells. *Proc. Soc. Exp. Biol. Med.*, **178**: 523-530.

Siegel, P.B. and Gross, W.B. (1980). Production and persistence of antibodies. 1. Directional selection. *Poultry Sci.*, **59**: 1-5.

Smith, E.M., Meyer, W.J.and Blalock, J.E. (1982). Virus-induced corticosterone in hypophysectomised mice. a possible lymphoid adrenal axis. *Science*, **218**: 1311-1312.

Subba Rao, D.S.V. and Glick, B. (1971). Effect of cold exposure on the immune response of chickens. *Poultry Sci.*, **56**: 992-996.

Sullivan, D.A. and Wira, C.R. (1979). Sex hormone and glucocorticoid receptor in the bursa of Fabricius of immature chickens. *J. Immunol.*, **122**: 2617-2623.

Thaxton, P. (1978). Influence of temperature on the immune response of birds. *Poultry Sci.*, **51**: 342-344..

Thaxton, P. and Briggs, D.M. (1972). Effect of immobilisation and formaldehyde on immunological responsiveness in young chickens. *Poultry Sci.*, **51**: 342-344.

Thaxton, P. and Siegel, H.S. (1973). Modification of high temperature and ACTH mediated immunosuppression by metyrapone. *Poultry Sci.*, **52**: 618-624.

Thaxton, P., Wyatt, R.D. and Hamilton, P.B. (1974). The effect of environmental temperature on parathyroid infection in neonatal chicken. *Poultry Sci.*, **53**: 88-94.

Turner, C.D. and Bagnara, J.T. (1976). General Endocrinology. W.B. Saunders Co., Philadelphia, PA.

Ubosi, C.O., Dunnington, E.A., Gross, W.B. and Siegel, P.B. (1985). Divergent selection for antibody response to sheep erythrocytes. Kinetics of primary and secondary immunisations. *Avian Dis.*, **29**: 347-355.

van der Zijpp, A.J. (1983). The effects of genetic origin, source of antigen and dose of antigen on the immune response of cockerels. *Poultry Sci.*, **62**: 205-211.

Zulkifli, I., Dunnington, E.A., Gross, W.B. and Siegel, P.B. (1994a). Food restriction early or later in life and its effect on adaptability, disease resistance, and immunocompetence of heat-stressed dwarf and nondwarf chickens. *Br. Poult. Sci.*, **35**: 203-214.

Zulkifli, I., Dunnington, E.A., Gross, W.B. and Siegel, P.B. (1994b). Inhibition of adrenal steroidogenesis, food restriction and acclimation to high ambient temperatures in chickens. *Br. Poult. Sci.*, **35**: 417-426.

Zulkifli, I. and Siegel, P.B. (1995a). Is there a positive side to stress? *World's Poult. Sci. J.*, **51**: 63-76.

Zulkifli, I. and Siegel, P.B. (1995b). The good and bad of stress. *Poult. Digest* **54**(11): 18-24.

RINGKASAN

TEKANAN, KEIMUNAN DAN KETAHANAN PENYAKIT DALAM AYAM ITIK : SUATU ULASAN

Gerak balas tekanan berpanjangan menyebabkan pengagihan semula sumber dengan kehasilan, kesihatan dan kesejahteraan sebagai kos biologinya. Sifat katabolisme gerak balas tekanan, terutama sekali melalui pengantaran kortikosteroid, mungkin membatas keimunan humoral dan berantarakan sel. Mekanisme pengimunotindasan tertekan-cetus mungkin termasuk pengubahsuaian kegiatan enzim, metabolisme asid nukleik, dan kadar pematangan limfosit, sintesis interleukin II, dan kematian sel terprogram. Ada banyak bukti yang menyarankan berlaku saling tindakan dwiarah di antara sistem imun dan neuroendokrin. Kajian dalam kedua-dua spesis avian dan mamalia menunjukkan yang tekanan boleh memberi kedua-dua pengaruh, iaitu baik dan buruk, terhadap ketahanan penyakit berjangkit dan bukan berjangkit. Fenomenon ini boleh disabitkan kepada kesan kortikosteroid samada terhadap patologi tertentu yang terlibat atau mekanisme pertahanan imunologi.