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History, changing scenarios and future strategies to induce moulting in laying hens

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Moulting is a natural phenomenon in birds during which they replace old plumage with new feathers, reduce feed intake, lose body weight and suspend reproduction. Moulting in laying hens can be induced by using photoperiods, feed deprivation or restriction or diets containing minerals or variable amounts of other ingredients. Induced moulting can result in higher egg production and improved quality. It reduces mortality, production costs and investments in new farms and hatcheries. While feed withdrawal has been a most effective way to induce moult in poultry birds, it is illegal on welfare grounds in the UK and Europe. This may have implications for the global poultry industry. Therefore, efforts to find a non feed removal method as a desirable alternative to induce moulting in poultry birds are underway in different countries. This paper reviews the history of induced moulting and its future implications by examining different methods that have been tested in the past and their potential to become a more acceptable alternative to feed removal method of inducing moulting in laying hens.

Keywords: moulting; welfare; induction; physiology

Introduction

The jungle fowl (Gallus gallus) experiences broodiness during its life, at which time the reproductive system involutes, egg production ceases and new feathers develop (Sherry *et al.,* 1980). During broody periods, the hen reduces food intake and loses weight by about 20%, which is termed 'spontaneous anorexia' (Mrosovsky and Sherry, 1980; Sherry *et al.,* 1980). The hen resumes feeding gradually after the chicks hatch and renews her feathers accordingly. One of the most extreme examples of spontaneous anorexia in birds is seen in male emperor penguins (*Aptenodytes forsteri*) who, during the Antarctic winter, are responsible for incubating eggs laid by their mates. During incubation, access to feed is very difficult and body weight losses of up to 40% may occur (Le Maho, 1977). However, it is a normal feature of all birds, including chickens, to survive on little or no

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food for much longer durations (Berry, 2003) and yet maintain themselves before returning from a non-productive to a productive cycle again.

Migrating birds, especially shorebirds, are known to fly non-stop for thousands of kilometres. These flights may last for 100 h (Piersma and Baker, 2000; Battley *et al.,* 2000), and the birds go without food or water during this time, relying exclusively on body stores, despite their high metabolic rates (Butler and Woakes, 1990).

The practice of induced moulting has been beneficial in extending the productive lives of hens which would otherwise be culled as soon as they reached a lower level of egg production. This paper reviews various different aspects of moulting which have been tested in the past and discusses their potential as a desirable method of inducing moult to sustain production and yet maintain their welfare.

Moulting, a natural phenomenon in different animal species

For most wild species of birds and other animals, moulting involves reproductive quiescence (Burton and Burton, 1980). In mammals, moulting is induced by a complexity of factors, including a natural rhythm, seasonal changes in the light duration, and hormones. In snakes, moulting is accomplished by loosening the skin around the lips, which is pushed back, allowing it to crawl out of its old skin. Elephant seals come ashore in their hundreds to moult in the latter half of the summer, which improves their appearance greatly. In Amphibians thyrotrophic hormones stimulate the thyroid gland, triggering the moulting process. In arthropods, moulting involves the secretion of hormones by the epidermis, resulting in the loosening and partial dissolving of the old cuticle, which splits, and allows the arthropod to emerge. A false scorpion moults four times during its two to three years of life. Insects can only increase in their linear dimensions at periodic intervals when the restricting exoskeleton is shed during moulting. Mayflies, after spending up to three years in a 'nymph' stage, emerge from the water, usually at night, and moult (shed their skin) into a winged form that usually moults again into an adult mayfly. In crabs, the male and female moult at different times and the males pair with the females when the latter has just cast their shells and are still soft. When a female moults she becomes more attractive to the males. Lobsters grow by periodic moulting of their hard external skeleton about eight times in the first year, two to three times in the next two years and only once after 3rd year. Nematode worms undergo four moults between hatching and maturity (Burton and Burton, 1980).

Induced moulting in avian species

Moulting in avian species is defined as the periodic shedding and replacement of feathers (Berry, 2003). Induced moulting in laying hens dates back to early nineteenth century (Rice, 1905; Rice *et al.,* 1908). Scientists investigated different methods for moult induction, and this practice gained popularity during 1930s. Most of the egg producers in California adopted induced moulting in 1950s. The practice of moulting continued to spread as the number of research papers being published in 1960s and 1970s increased. More recently, induced moulting has been adopted in many egg producing regions of the world as a tool to rejuvenate spent hens (Bell, 2003).

Commercially it is common that layer flocks produce eggs for a 1 year laying cycle and then are sold. Egg production and quality become relatively low towards the end of a laying cycle, particularly if the end of the lay coincides with the hot weather. Small eggs are laid at the start of egg production, which reduces net farm income (Koelkebeck *et al.,* 1993; Yousaf, 1998). With induced moulting, flocks lay for an additional laying year, thereby spreading fixed costs over a longer time and over more units of production. It is estimated that today more than 75% of all flocks are moulted in the USA as a part of a regular replacement programme (Holt, 2003).

Physiological mechanisms of moulting

During annual rest in laying hens blood lipids decrease as ovary and oviduct decrease in size, similar to those found in the immature state. Lowered reproductive activity has been found to be a prerequisite for moult to occur, with thyroid playing a role in its onset. The most predictable physiological changes observed in moulted hens are associated with ovarian and thyroid activity (Brake and Thaxton, 1979). A general antagonism between the pituitary-ovarian and pituitary-thyroid axis seems to be of crucial importance to the control of feather renewal during the induced cessation of egg laying (Decuypere and Verheyen, 1986). Several hormones have been suggested as candidates to control the process of moulting. Moult induction is accompanied by increases first in thyroxine (T_4) and then in T_3 (Verheyen *et al.,* 1983). The mechanism of feather replacement or natural moulting is expressed as the ovary became atretic, resulting in the decreased release of oestrogen which discontinues the existing suppressed activation of feather papillae. Thyroxin/progesterone activates the feather papillae in the formation of an underlying new feather that ultimately expelled its predecessor. The fact that old feathers are gradually expelled by newly developing ones during moulting suggests that the hormonal control of moulting is associated with a stimulation of the feather papillae. Conversely, oestrogens are generally accepted as inhibiting the feather follicle activity (Stake *et al.,* 1979). Elevated levels of corticosteroids are reported to cause cessation of egg laying as well as gonadal atrophy (van Tienhoven, 1981).

Moulting methods

Research into moulting strategies has been actively since the 1960s and 1970s, and it is currently gaining more attention in replacing traditional feed removal programmes. Several successful methods of induced moulting have been used to recycle laying hens. The majority of which require an optimum weight loss of 25-35% to achieve maximum egg production during the post moult period. This weight loss is caused primarily by a reduction in organ weights and utilization of body reserves as nutrients during periods of moulting treatments. Excessive body weight loss, as seen in feed withdrawal methods, results in hunger, lowered immunity and higher mortality, while laying hens moulted by non-feed withdrawal exhibit lower body weight loss, better immunity, less mortality and sequential rejuvenation of the reproductive system. Most common methods of induced moulting can be described under the following 4 subsections:

FEED REMOVAL OR /AND FEED RESTRICTION

Conventional feed deprivation or feed restriction procedure is the most widely used practise in poultry production because it is a simple, practicable and economical technique that can be used in combination with light and/or water restriction (Rice *et al.,* 1908; Hembree *et al.,* 1980; Hussein, 1996; Yousaf, 1996; Yousaf, 1998; Koelkebeck *et al.,* 2001; Bell, 2003; Biggs *et al.,* 2004; Chowdhury *et al.,* 2004; El-Deek and Al-

Harthi, 2004; Oguike *et al.,* 2004; Kubena *et al.,* 2005; Khoshoei and Khajali, 2006). During feed deprivation, the birds are able to utilise their excess body reserves as nutrients for their survival during starvation while going out of production. However, feed deprivation is known to cause catabolism which can lead to abnormal physiological mechanisms including reduced immunity, undesirable behaviour and even mortality of birds. Feed restriction of varying degrees could be a possible alternative to feed deprivation method but its effectiveness depends upon the extent of feed restriction and the ingredient and nutrient density of relevant feeds that are used to induce moulting in laying hens.

VARIABLE NUTRIENT DIETS

Researchers have recently used thyroactive proteins (Kuenzel *et al.,* 2005), different ratios of alfalfa (Donalson *et al.,* 2005; Ricke, 2003; Woodward *et al.,* 2005; Kim *et al.,* 2006; McReynolds *et al.,* 2006), melengestrol acetate (Koch *et al.,* 2005a; 2005b), alfalfa and oligosaccharide (Kim *et al.,* 2006) for inducing moulting in poultry birds. Alfalfa can used in induced moulting of laying hens due to its higher crude protein and calcium content, along with its slow gut flow rate, resulting in better digestion and microbial fermentation. Although diets varying in nutrient density have been used successfully in moulting birds in different situations, it is difficult to pinpoint a single nutrient or feed type for this purpose. Also the deficiency of a single nutrient could cause potential damage to the bird health.

FEED ADDITIVES

Induction of moult through dietary mineral additives such as Cu, Zn (Stevenson and Jackson, 1984), Na (Harms, 1981), or Al (Hussein *et al.,* 1989) have been practiced by various scientists in the past to enhance the post-moult production. Use of high levels of either aluminium salt (Lipstein and Hurwitz, 1982; Hussein *et al.,* 1989; Hussein, 1996; Yousaf, 2004; Yousaf and Ahmad, 2006) or dietary zinc (Cantor and Johnson, 1984; Yousaf *et al.,* 1998; El-Deek and Al-Harthi, 2004; Moore *et al.,* 2004; Ocak *et al.,* 2004; Ahmed *et al.,* 2005; Yousaf and Ahmad, 2006; Koch *et al.,* 2007; Koelkebeck and Anderson, 2007) have been successfully used. However, supplementing low levels of dietary zinc combined with reduced calcium levels in the diet have also induced moulting successfully in laying hens (Cantor and Johnson, 1984; Breeding *et al.,* 1992; Yousaf, 1998; Ricke *et al.,* 2001). The use of a low sodium diet (Naber *et al.,* 1984; Said *et al.,* 1984) is equally effective as a feed restriction technique for inducing moult. Copper is used as an effective moulting agent (Pennington and Calloway, 1973; Davis, 1974; Griminger, 1977; Pearce *et al.,* 1983; Stevenson and Jackson, 1984, Yousaf, 1998, Yousaf, 2004). Supplementation of minerals has resulted in better post-moult production performance in laying hens as compared to a control group. However, induced moulting by high dietary minerals has raised public health concerns regarding the potential residues of these minerals in eggs and meat, which may have implications for human health. This risk of high mineral residues can be minimised by using low mineral diets and yet induce moulting in egg laying hens.

HORMONES

Hormone-induced moulting involves the use of the gonadotrophin-releasing hormone (Gn-RH) agents (Dickerman and Bahr, 1989) and Leuprolide acetate (Burke and Attia, 1994). Higher egg production had been reported in moulted layers following progesterone injections as compared to moult induction by feed restriction (Adams, 1955). Progesterone administration has been successfully practiced for induced moulting of laying hens (Adams, 1956; Hansen, 1960; Furr *et al.,* 1973; Mashaly and

Wentworth, 1974; Johnson and Van Tienhoven, 1981; Etches *et al.,* 1984; Herremans *et al.,* 1988, Yousaf, 1998). Laying hens can be effectively moulted by thyroxin hormone (Lofts and Murton, 1972; Pethes *et al.,* 1982; Verheyen *et al.,* 1983a; Sekimoto *et al.,* 1987; Queen *et al.,* 1997; Herremans *et al.,* 1988; Yousaf *et al.,* 1998; Keshavarz and Quimby, 2002). Feather replacement was higher in progesterone administered hens, but post-moult production was lower as compared to the feed withdrawal method. Induced moulting by hormones does not appear to be a practical method for the poultry industry because of variable production performance, intensive hen handling and consequently high costs. Therefore, other non-feed withdrawal methods seem to suit better for induced moulting because of their simple operations and high post-moult hen performance with enhanced economic returns.

Justification and benefits

Induced moulting can be justified on the basis of its positive effects in the form of enhanced productivity, reduced costs and reduced industry investments in breeder farms, rearing farms, and hatcheries. Economic and welfare benefits of an induced moult include the extended use of approximately 50% fewer hens in commercial egg flocks with fewer male chicks hatched (Bell *et al.,* 2004). It is reported that in the USA, almost all the layer flocks are moulted at least once and often twice in their life time. Laying hens from moulted parent flocks are preferred by poultry farmers because of their higher body weight.

Most researchers have reported that induced moulting improves the post-moult performance of the laying hens when compared to the pre-moult performance. Improvements in egg quality parameters are very evident in layers following an induced moult. These improvements include the larger eggs, improved shell quality and enhanced rate of egg production. There is also a marked increase in the internal egg quality as measured by the Haugh units (Zimmermann *et al.,* 1987). In general, albumen quality, candled grade, shell thickness, specific gravity and shell texture improve when poultry flocks are moulted (Hansen, 1967). Induced moulting results in an increase in egg production, greater number of intact eggs, enhanced egg mass and shell quality. A decrease was noted in egg breakage, mortality and culling (Bar *et al.,* 2001). It was observed that egg weight and shell thickness increases following induced moulting (Yousaf, 2006a, Yousaf, 2006b).

The most significant difference in different egg production cycles is for the egg weight and number. Egg weight remains below 60 g up to 20 weeks in the first production cycle. During the initial 10 weeks of lay, egg weights average only 52.3 g as compared to 62.6 g and 63.4 g per egg in first, second and third production cycles, respectively. At 35 week of production, egg weights are 57.4, 63.4, and 63.7 g per egg for the three cycles, respectively (Bell, 2003). The average increase in egg weight in second or third egg cycles can partly be attributed to the increase in bird age and size. However, comparison between the moulted and unmoulted birds of the same age and size also suggest that moulted birds produce bigger and better eggs than unmoulted ones (Bar *et al.,* 2003). In the USA egg market, the eggs from the second and third cycles have a higher level of profit per dozen of eggs than those from the first cycle flocks (Bell, 2003).

In laying hens, in order to minimize the age-related declines in shell quality and egg production, cessation of egg laying can be induced through moult, which involves feed and light restriction. Induced moulting lengthens productive life of flocks and provides a means of optimizing the use of resources with enhanced returns on investments. Under the right economic conditions, the economically useful life of a laying flock may be extended from less than 80 weeks to 110 weeks or even to 140 weeks through the judicious use of the moulting process.

Moulting programmes involve an estimated 75 to 80% of the commercial flocks in the USA. Approximately one third of the profits of a flock are estimated to come from moulted birds (Holt, 2003). At any point in time, 25 to 30% of the layer are either in a moult or have been moulted earlier. Induced moulting is used as a part of a programme to optimize pullet replacement on commercial layer farms. With current management systems, farms using the single-cycle (non moulted) programme would require 8.4 new flocks per layer house over a 10-year period, whereas only 5.7 flocks would be required for a typical two-cycle (one moult) flock system (Bell, 2003).

All-pullet flocks system require an additional 47% chicks each year which in turn, would require a similar increase in breeder flocks, breeder farms, hatcheries, and pullet-rearing farms. One hundred million more male chicks would have to be destroyed each year, and 47% more spent hens would have to be removed. An all-pullet industry would produce higher percentages of the less popular egg sizes (medium and small), which are less undesirable to retailers. Egg quality would suffer as egg producers would push their flock's ages beyond the limits of good egg quality. Egg producers would have less flexibility to adjust production to meet the market demand (Bell, 2003).

Induced moulting by feed withdrawal, animal welfare issues and future strategy

An ideal moulting method should be simple and cost-effective. Also it must be able to reduce mortality and improve subsequent performance of laying birds (Swanson and Bell, 1974b). The programmes mostly used in commercial flocks around the world involve feed deprivation over a 7 to 14 day period, causing body weight loss of 25 to 35%, followed by a rest period and then re-stimulation of egg production. Such methods have become standard practice for induced moulting (Webster, 2003).

In recent years, the induction of moult by feed withdrawal has become more of a concern to the poultry industry in the UK and Europe due to the hen welfare and human food safety reasons (Bell, 2003; Gast and Ricke, 2003). Almost all the egg producers in USA still moult their flocks by the feed removal method (UEP, 2006). Feed deprivation results in hunger, which lowers immunity and increases mortality losses of the birds. The mortality rates are greater during the moulting period when the hens are deprived of feed as compared to non feed removal methods. Despite the availability of alternative methods, feed withdrawal is still considered the most effective, practical and economical method in the poultry industry (Yousaf, 1998). The percentage of eggs contaminated with *Salmonella enteritidis* (SE) increases when flocks are moulted by feed withdrawal versus non-moulted hens in commercial flocks (Holt, 1995). The endocrine changes observed in the fasted hens include a large and temporary increase in the circulating levels of corticosterone (Etches *et al.,* 1983) which in turn affects the immunological defences against infection and disease by reducing hen's cell-mediated immune response. Fasting also reduces the ability of the hen to resist pathogenic colonization of the gut (Webster, 2003). Additionally, induced moulting by feed withdrawal not only reduces resistance to pathogens but also resulted in a decline of mineralization of the medullary tibia and the humerus although a gradual recovery during the post-moult period was observed (Mazzuco and Hester, 2005).

While the feed withdrawal method has been the most effective in inducing moulting, it is deemed unacceptable on hen welfare grounds. Therefore, the poultry scientists have the responsibility to develop and implement suitable alternatives if induced moulting of laying hens is considered essential by the poultry industry (AVMA, 2002).

In the UK and Europe, induced moulting by feed withdrawal is strictly banned (DEFRA, 1994). Induced moulting is still being practiced in many countries, including USA, by feed withdrawal, and may continue in the future. However, it is possible to use non-feed removal methods which do not interfere with the bird welfare to moult poultry flocks in the UK (Edge, 1998). Recently, the initiative taken by the United Egg Producers (UEP) to stop feed withdrawal moulting practices has led to the development of non-feed withdrawal moulting programmes where hens continue to eat during moulting period, stop producing eggs and perform better in the subsequent production cycle. Therefore, the need for an alternative moulting method has dramatically increased with the recent change in the United Egg Producers guidelines where feed withdrawal can no longer be used to induce moult in laying hens.

Alternatives

The alternative of feed withdrawal involves procedures of either feeding deficient levels of nutrients or the addition of substances in the feed which inhibit egg production. The nutrient restriction procedure is the method of choice in countries that have disallowed feed removal programmes. Nutrient restrictions have been successfully employed using marginal levels of salt or sodium (Naber *et al.,* 1984), calcium (Martin *et al.,* 1973) and low-nutrient diets (Bell *et al.,* 1976, Yousaf, 1998). Various high concentrations of minerals have been used to halt egg production. Examples of these include zinc (Hussein *et al.,* 1988; Cantor and Johnson, 1984; Yousaf, 1998), aluminium (Lipstein and Hurwitz, 1982; Hussein *et al.,* 1989; Yousaf, 2004; Yousaf and Ahmad, 2006), and potassium iodide (McCormick and Cunningham, 1987; Hussein *et al.,* 1989). Additional research has reported that the use of various additives such as progesterone and enheptin can help induce moulting. Good welfare practices require that moulting hens should always have access to a nutritious and palatable maintenance diet, until the flock reaches a pre-production physiological state. Research conducted by academics, industry and the scientific community has demonstrated that a return to the pre-production physiological state can be achieved by providing a maintenance diet. This diet is designed to bring the flock into a non-laying period and rejuvenation of oviduct (UEP, 2006).

Conclusion

Induced moulting is a world-wide practice in poultry industry which significantly increase the productive lives of laying hens and hence the profits of poultry farmers. However, due to the hen welfare concerns regarding the commonly used feed withdrawal method, the practice of induced moulting has become controversial. No doubt, poultry farmers will always need to moult their flocks and for this reason they would welcome a more desirable method of moulting to maintain a well managed, cost-effective and sustainable egg production system. Therefore, it is essential to test and validate the suitability of a non feed removal method by examining the most appropriate levels of feed restriction, photoperiod and feed additives for inducing moult and improving subsequent hen welfare, egg production and economics.

References

ADAMS, J.L. (1955) Progesterone-induced unseasonable moult in single comb White Leghorn pullets. *Poultry Science* **34**: 702-707.

ADAMS, J.L. (1956) A comparison of different methods of progesterone administration to the fowl in affecting egg production and moult. *Poultry Science* **35**: 323-326.

AHMED, A.M.H., RODRIGUENZ-NAVARRO, A.B., VIDAL, M.L., GOUTRON, J., GARCIA-RUIZ, J. M. and NYS, Y. (2005) Changes in the eggshell properties, crystallographic texture and in matrix proteins induced by moult in hens. *British Poultry Science* **46**: 268-279.

AVMA (2002) New position on induced molting wins the favour. *Journal of the American Veterinary Medical Association* (www.avma.org.onlnews/javma/sep02/020901d.asp).

BAR, A., RAZAPHKOVSKY, V., WAX, E. and MALKA, Y. (2001) Effect of age at molting on post-molting performance. *Poultry Science* **80**: 874-878.

BAR, A., RAZAPHKOVSKY, V., SHINDER, V. and VAX, E. (2003) Alternative procedures for molt induction: Practical aspects. *Poultry Science* **82**: 543-550.

BATTLEY, P.F., PIERSMA, T., DIETZ, M.W., TANG, S., DEKINGA, A. and HULSMAN, K. (2000) Empirical evidence for differential organ reductions during trans-oceanic bird flight. *Proceedings of the Royal Society* **267**: 191–195.

BELL, D.D., SWANSON, M.H. and JOHNSTON, G. (1976) A comparison of force molting methods. Progress in Poultry. University of California Cooperative Extension, Davis, CA.

BELL, D.D. (2003) Historical and current moulting practices in the U.S. table egg industry. *Poultry Science* **82**: 965-970.

BELL, D.D., CHASE, B., DOUGLASS, A., HESTER, P., MENCH, J., NEWBERRY, R., SHEA-MOORE, M., STANKER, L., SWANSON, J. and ARMSTRONG, J. (2004) UEP uses scientific approach in its establishment of welfare guidelines. *Feedstuffs* **76**(1): 13-21.

BERRY, W.D. (2003) The physiology of induced molting. *Poultry Science* **82**: 971-980.

BIGGS, P.E., PERSIA, M.E., KOELKEBECK, K.W. and PARSONS, C.M. (2004) Further evaluation of non feed removal methods for moulting programs. *Poultry Science* **83**: 745-752.

BRAKE, J. and THAXTON, P. (1979) Physiological changes in caged layers during a forced moult. 1. Body temperature and selected blood constituents. *Poultry Science* **58**: 699-707.

BREEDING, S.W., BRAKE, J. and GARLICH, J.D. (1992) Moult induced by dietary zinc in a low calcium diet. *Poultry Science* **71**: 168-180.

BURKE, W.H. and ATTIA, Y.A. (1994) Moulting single comb White Leghorns with the use of the Lupron Depot formulation of leuprolide acetate. *Poultry Science* **73**: 1226-1232.

BURTON, M. and BURTON, R. (1980). *The New International Wildlife Encyclopedia*. N.C.L.C. Limited, London UK.

BUTLER, P.J. and WOAKES, A.J. (1990) The physiology of bird flight. In: *Bird Migration* (ed. E. Gwinner), pp. 300–318. Berlin: Springer.

CANTOR, A.H. and JOHNSON, T.H. (1984) Inducing pauses in egg production of Japanese quail with dietary zinc. *Poultry Science* **63** (Suppl. 1): 10 (Abstr.).

CHOWDHURY, V.S., NOSHIBORI, M. and YOSHIMURA, Y. (2004) Changes of the mRNA expression of TGFβ receptor types II and III in the interior pituitary during induced molting in hens. *Journal of Poultry Science* **41**: 140-146.

DAVIS, G.K. (1974) High level copper feeding of swine and poultry. *Federation Proceedings of American Societies for Experimental Biology* **33**: 1194-1196.

DECUYPERE, E. and VERHEYEN, G. (1986) Physiological basis of induced molting and tissue regeneration in fowls. *World's Poultry Science Journal* **42**: 56-68.

DEFRA (1994) http://www.opsi.gov.uk/si/si1994/Uksi_19942126_en_1.htm.

DICKERMAN, R.W. and BAHR, J.M. (1989) Moult induced by gonadotrophin releasing hormone agonist as a model for studying endocrine mechanisms of moulting in laying hens. *Poultry Science* **68**: 1402-1408.

DONALSON, L.M., KIM, W.K., WOODWARD, C.L., HERRERA, P., KUBENA, L.F., NISBET, D.J. and RICKE, S.C. (2005) Utilizing different ratios of alfalfa and layer ration for molt induction and performance in commercial laying hens. *Poultry Science* **84**: 362-369.

EDGE, S. (1998) Moulting laying hens. ADAS Gleadthorpe Research Centre, Mansfield, Notts, UK.

EL-DEEK, A.A. and AL-HARTHI, M.A. (2004) Postmoult performance of broiler breeder hens associated with moult induced by feed restriction, high dietary zinc and fasting. *International Journal of Poultry Science* **3**(7): 456-462.

ETCHES, R.J., WILLIAMS, J.B. and RZASA, J. (1983) Corticosterone and nutritionally induced ovarian regression in the hen. *Poultry Science* **62**: 1417 (Abstr.).

ETCHES, R.J. (1984) Maturation of ovarian follicles in Cynnghan. *Reproductive Biology of Poultry* pp. 51-73.

FURR, B.J.A., BONEY, R.C., ENGLAND, F.J. and CUNNINGHAM, F.J. (1973) Luteinizing hormone and progesterone in peripheral blood during the ovulatory cycle of the hen (Gallus domesticus). *Endocrinology* **57**: 159-169.

GAST, R.K. and RICKE, S.C. (2003) Symposium: Current and future prospects for induced moulting in laying hens. *Poultry Science* **82**: 964.

GRIMINGER, P. (1977) Effect of dietary copper sulphate on egg production and shell thickness. *Poultry Science* **56**: 359-361.

HANSEN, R.S. (1960) The effect of method of force moulting on reproductive performance of chickens. *Poultry Science* **39**: 1257 (Abstr.).

HANSEN, R.S. (1967) Periodic forced molting for a two-year lay. In: *Pacific Poultryman* (July), Watt Publishing, Mt. Morris, IL.pp. 24, 25, 60.

HARMS, R.H. (1981) Effect of removing salt, sodium, or chloride from the diet of commercial layers. *Poultry Science* **70**: 333-336.

HEMBREE, D.J., ADAMS, A.W. and CRAIJ, J.V. (1980) Effects of force moulting by conventional and experimental light restriction method on performance and agonistic behaviour of hens. *Poultry Science* **59**: 215-223.

HERREMANS, M., VERHEYEN, M. and DECUYPERE, B. (1988) Effect of temperature during induced moulting on plumage renewal and subsequent production. *British Poultry Science* **29**: 853-861.

HOLT, P.S. (2003) Moulting and Salmonella enteritidis infection: The problem and some solutions. *Poultry Science* **82**: 1008-1010.

HUSSEIN, A.S. (1996) Induced moulting procedures in laying fowl. *World's Poultry Science Journal* **52**: 175-187.

HUSSEIN, A.S., CANTOR, A.H. and JOHNSON, T.H. (1988) Use of high dietary levels of aluminium and zinc for inducing pauses in egg production of Japanese quails. *Poultry Science* **67**: 1157-1165.

HUSSEIN, A.S., CANTOR, A.H. and JOHNSON, T.H. (1989) Comparison of the use of dietary aluminium with the use of feed restriction for forced moulting laying hens. *Poultry Science* **68**: 891-896.

JOHNSON, A.L. and VAN TIENHOVEN, A. (1981) Plasma concentrations of sex steroids and LH during the ovulatory cycle of the hen, Gallus domesticus. *Biology of Reproduction* **23**: 386-393.

KESHAVARZ, K. and QUIMBY, F.W. (2002) An investigation of different moulting techniques with an emphasis on animal welfare. *Journal of Applied Poultry Research* **11**: 54-67.

KHOSHOEI, E.A. and KHAJALI, F. (2006) Alternative induced-moulting methods for continuous feed withdrawal and their influence on postmoult performance of laying hens. *International Journal of Poultry Science* **3(7)**: 47-50.

KIM, W.K., DONALSON, L.M., MITCHELL, A.D., KUBENA, L.F., NISBET, D.J. and RICKE, S.C. (2006) Effects of alfalfa and fructooligosaccharide on molting parameters and bone qualities using dual energy X-ray absorptiometry and conventional bone assays. *Poultry Science* **85**: 15-20.

KOCH, J.M., MORITZ, J.S., LAY, D.C. and WILSON, M.E. (2005a) Melengestrol acetate in experimental diets as an effective alternative to induce a decline in egg production and reversible regression of the reproductive tract in laying hens. I. Determining an effective concentration of melengestrol acetate. *Poultry Science* **84**: 1750-1756.

KOCH, J.M., MORITZ, J.S., SMITH, D.L., LAY, D.C. and WILSON, M.E. (2005b) Melengestrol acetate as an effective alternative to induce a decline in egg production and reversible regression of the reproductive tract in laying hens. II. Effects on postmolt egg quality. *Poultry Science* **84**: 1757-1762.

KOCH, J.M., LAY, D.C., MACMUNN, K.A., MORITZ, J.S. and WILSON, M.E. (2007) Motivation of hens to obtain feed during a molt induced by feed withdrawal, wheat middlings or melengestrol acetate. *Poultry Science* **86**: 614-620.

KOELKEBECK, K.W., PARSONS, C.M., LEEPER, R.W. and WANG, X. (1993) Effect of supplementation of a low corn moult diet with amino acids on early postmoult laying hen performance. *Poultry Science* **72**: 1528-1536.

KOELKEBECK, K.W., PARSONS, C.M., DOUGLAS, M.W. , LEEPER, R.W., JIN, S., WANG, S., ZHANG, Y. and FERNANDEZ, S. (2001) Early postmolt performance of laying hens fed a low-protein corn molt diet supplemented with spent hen meal. *Poultry Science* **80**: 353-357.

KOELKEBECK, K.W. and ANDERSON, K.E. (2007) Molting layers-alternative methods and their effectiveness. *Poultry Science* **86**: 1260-1264.

KUBENA, L.F., BYRD, J.A., MOORE, R.W., RICKE, S.C. and NISBET, D.J. (2005) Effects of drinking water treatment on susceptibility of laying hens to Salmonella enteritidis during forced moult. *Poultry Science* **84**: 204-211.

KUENZEL, W.J., WIDEMAN, R.F., CHAPMAN, M., GOLDEN, C. and HOOGE, D.M. (2005) A practical method for induced moulting of caged layers that combines full access to feed and water, thyroactive protein, and short day length. *World's Poultry Science Journal* **61**: 599-624.

LE MAHO, Y. (1977) The emperor penguin: A strategy to live and breed in the cold. *American Science Journal* **65**: 680–693.

LIPSTEIN, B. and HURWITZ, S. (1982) The nutritional value of sewage-grown, alum-flocculated micractnium algae in broiler and layer diet. *Poultry Science* **60**: 2628-2638.

LOFTS, B. and MURTON, R.K. (1972) Reproduction in birds. *Avian biology*. Academic press, New York.

MARTIN, G.A., MORRIS, T.B., GEHLE, M.H. and HARWOOD, D.G. (1973) Force- molting by limiting calcium intake. *Poultry Science* **52**: 2058.

MASHALY, M.M. and WENTWORTH, B.C. (1974) A profile of progesterone in turkey sera. *Poultry Science* **53**: 2030-2035.

MAZZUCO, H. and HESTER, P.Y. (2005) The effect of an induced moult and a second cycle of lay on skeletal integrity of White Leghorns. *Poultry Science* **84**: 771-781.

MCCORMICK, C.C. and CUNNINGHAM, D.L. (1987) Performance and physiological profiles of high dietary zinc and fasting as methods of inducing a forced rest: direct comparison. *Poultry Science* **66**: 1007-1013.

MCREYNOLDS, J.L., MOORE, R.W., KUBENA, L.F, BYRD, J.A., WOODWARD, C.L., NISBET, D.J. and RICKE, S.C. (2006) Effect of various combinations of alfalfa and standard layer diet on susceptibility of laying hens to Salmonella enteritidis during forced molt. *Poultry Science* **85**: 1123-1128.

MOORE, R.W., PARK, S.Y., KUBENA, L.F., BYRD, J.A., MCREYNOLDS, J.L., BURNHAM, M.R., HUME, M.E., BIRKHOLD, S.G., NISBET, D.J. and RICKE, S.C. (2004) Comparison of zinc acetate and propionate addition on gastrointestinal tract fermentation and susceptibility of laying hens to Salmonella enteritidis during forced molt. *Poultry Science* **83**: 1276-1286.

MROSOVSKY, N. and SHERRY, D. (1980) Animal anorexias. *Science* **207**: 837–842.

NABER, E.C., LATSHAW, J.D. and MARSH, G.A. (1984) Effectiveness of low sodium diets for recycling of egg production type hens. *Poultry Science* **63**: 2419-2429.

OGUIKE, M.A., IGBOELI, G., IBE, S.N. and UZOUKWU, M. (2004) Effect of day length and feed/water regime on induction of feather moult and subsequent laying performance in the domestic fowl. *International Journal of Poultry Science* **3** (8): 507-512.

OCAK, N., SARICA, M., ERENER, G. and GARPOGLU, A.V. (2004) The effect of body weight prior to moulting in brown laying hens on egg yield and quality during second production cycle. *International Journal of Poultry Science* **3** (12): 768-772.

PEARCE, J., JACKSON, N. and STEVENSON, M.H. (1983) The effects of dietary intake and of dietary concentration of copper sulphate on the laying domestic fowl: effects on some aspects of lipid, carbohydrates and amino acid metabolism. *British Poultry Science* **24**: 337-348.

PENNINGTON, J.T. and CALLOWAY, D.H. (1973) Copper content of foods. *Journal of American Dietary Association* **63**: 143-153.

PETHES, G.Y., SZELENYI, A. and PEEZELY, P. (1982) Changes in the plasma concentrations of thyroid hormones and sexual steroids during forced moult of male and female domestic chickens. *Acta Veterineria Academica Hungarica* **30**: 193-201.

PIERSMA, T. and BAKER, A.J. (2000) Life history characteristics and the conservation of migratory shorebirds. In: *Behaviour and Conservation* (ed. L.M. Gosling and W.J. Sutherland), pp. 105–124. Cambridge: Cambridge University Press.

QUEEN, W.H., CHRISTENSEN, V.L. and MAY, J.D. (1997) Supplemental thyroid hormone and moulting in turkey breeder hens. *Poultry Science* **76**: 887-893.

RICE, J.E. (1905) In: *The Feeding of Poultry; The Poultry Book*. W.D. Johnson and G.O. Brown, ed. Doubleday, New York.

RICE, J.E., NIXON, C. and ROGERS, C.A. (1908) The moulting of fowls. Bulletin No. 258. Cornell University, Ithaca, NY.

RICKE, S.C., KWON, Y.M., WOODWARD, C.L., BYRD, J.A., NISBET, D.J. and KUBENA, L.F. (2001) Limitation of Salmonella enteritidis colonization by diets containing low calcium and low zinc. *Poultry Science* **80** (1): 262 (Abstr.).

RICKE, S.C. (2003) The gastrointestinal tract ecology of salmonella enteritidis colonization in molting hens. *Poultry Science* **82**: 1003-1007.

SAID, M.W., SULLIVAN, T.W., BIRD, H.R. and SUNDE, M.L. (1984) A comparison of the effect of two force moulting methods on performance of two commercial strains of laying hens. *Poultry Science* **63**: 2399-2403.

SEKIMOTO, K., IMAI, K., SUZUKI, M., TAKIKAWA, H., HOSHINO, N. and TOTSUKA, K. (1987) Thyroxin-induced moulting and gonadal function in laying hens. *Poultry Science* **66**: 752-756.

SHERRY, D.F., MROSOVSKY, N. and HOGAN, J.A. (1980) Weight loss and anorexia during incubation in birds. *Journal of Comparative Physiology and Psychology* **94**: 89-98.

STAKE, P.E., FREDERICKSON, T.N., OKULICZ, W., SHIPPEE, R.L. and FOURNIER, D.J. (1979) Tamoxifen induced forced-rest/molt in laying hens. *Poultry Science* **58**:1111

STEVENSON, M.H. and JACKSON, N. (1984) Comparison of dietary hydrated copper sulphate, dietary zinc oxide and a direct method for inducing moult in laying hens. *British Poultry Science* **25**: 505-517.

SWANSON, M.H. and BELL, D.D. (1974a) Force molting of chickens-I Introduction. Leaflet 2649. University of California, Davis, CA.

SWANSON, M.H. and BELL, D.D. (1974b). Force molting of chickens. 2. Methods. Univ. California Coop. Ext. Bull. AXT-411.

UEP, 2006. United Egg Producers animal husbandry guidelines for U.S. egg laying flocks. 2006 edition.

VAN TIENHOVEN, A. (1981) Neuroendocrinology of avian reproduction with special emphasis on the reproductive cycle of the fowl (Gallus domesticus). *World's Poultry Science Journal* **37**: 155-176.

VERHEYEN, G., DECUYPERE, E., KUHN, E.R., FONTAINE, G. and DE GROOTE, G. (1983a) Moult induction in the hen. Effect of different methods on some performance traits and on thyroid hormone, prolactin. Ca, P, Na, and protein concentrations in blood serum. *Reeub de I, Agriculture* **36**: 1535-1559.

WEBSTER, A.B. (2003) Physiology and behavior of the hen during induced moult. *Poultry Science* **82**: 992-1002.

WOODWARD, C.L., KWON, Y.M., KUBENA, L.F., BYRD, J.A., MOORE, R.W., NISBET, D.J. and RICKE, S.C. (2005) Reduction of Salmonella enteritidis colonization and invasion by an alfalfa diet during moult in Leghorn hens. *Poultry Science* **84**: 185-193.

YOUSAF, M. (1996) The impact of induced moult on the hormonal and haematochemical profile of the layers in the third production cycle. M.Sc. Thesis, Dept. of Poultry Husbandry Univ. of Agri., Faisalabad, Pakistan.

YOUSAF, M., AHMAD, N., AKRAM, M., ZIA-UR-REHAMAN (1996) Effect of molting on the haematochemical and hormonal changes in layers reared under different management conditions. Proceedings of Poultry Congress, New Delhi, India, Sept. 5, 1996.

YOUSAF, M. (1998) Comparative study of induced moult methods in relation to plumage renewal and productive performance of layers under cage and litter floor systems. Ph.D. thesis, Department of Poultry Science, University of Agriculture, Faisalabad, Pakistan.

YOUSAF, M., AHMAD, N., AKRAM, M., ZIA-UR-REHAMAN (1998) Changes in the concentration of various blood plasma parameters and hormones as influenced by induced moult in White Leghorn layers. *Pakistan Veterinary Journal* **18** (1): 36-42.

YOUSAF, M. (2004) Influence of different copper and aluminium levels on feather renewal and production characteristics of the layers in the second production cycle. Research project report submitted to Pakistan Science Foundation, Islamabad, Pakistan.

YOUSAF, M. (2005) Secrets of Feather Development. *World Poultry* **21(**3):16-17.

YOUSAF, M. (2006a) Influence of different copper and aluminium levels on organ weights, feather renewal and production performance of molted layers. *Pakistan Journal of Arid Agriculture* **9**(1): 35-39.

YOUSAF, **M. and AHMAD, N.** (2006) Effects of housing systems on productive performance of commercial layers following induced molting by aluminium oxide supplementation. *Pakistan Veterinary Journal* **26**(3): 101-104.

YOUSAF, M. (2006b) Induced molting: Tips for success. *Poultry International* **45**(4): 36-40.

ZIMMERMANN, N.N., ANDREWS, D.K. and MAGGINNIS, J. (1987) Comparison of several induced moulting methods on subsequent performance of Single Comb White Leghorn hens. *Poultry Science* **66**: 408-417.