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Review Article

Nutritional modulation of health, egg quality and environmental pollution of the layers

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ABSTRACT

World egg production and consumption have been increasing for the past decades. Traditional strategies in poultry nutrition have made vital contributions to this great growth in quantity. However, current global issues should be considered in modern egg production such as growing populations and food security, food safety and quality, limited resources and environmental problems. The development of knowledge of poultry nutrition and modern biotechnology provides novel nutritional approaches to closely fit the requirement of pullets and laying hens, which will consequently decrease the nutrition excretion and maintain the lower cost of feed. Nutrition has also been widely accepted as a strategy to influence health and diseases of laying hens. The maintenance of good health is an important prerequisite for improving productivity and egg quality. In addition, there are many measures and strategies for minimizing the incidence of egg defects and providing a choice of lifestyle to enhance human health. This paper reviews current research progress on developing innovative technologies and strategies to maximize animal health and performance, improve the quality of egg products and minimize pollution caused by poultry production.

1. Introduction

The poultry industry is one of the fastest growing animal industries globally. The world egg production reached 68.26 Mt in 2013, with an increase of 94.6% from 35.07 Mt in 1990 (FAOSTAT, 2015). Poultry meat and eggs have been suggested as the most important source of food protein for the world population for decades (Magdelaine, 2011). Together with the rapid growth of poultry industry, some global issues impacting on poultry production are becoming increasingly challenging. The world population is expected to reach 9 billion by year 2050, which indicates that the demand for food will increase continuously in the upcoming decades. Meanwhile, food producers are experiencing greater competition for limited land, water and energy sources (Godfray et al., 2010). As for the poultry industry, egg production is now hampered by a heavy shortage of feed ingredients. In addition, pollution problems of animal production show the trend of slowing down the rate of development because of the growing awareness of environmental protection. Thus, to meet the severe challenge, the egg industry should inevitably develop in a more sustainable way, aiming to maximize production at the lowest cost and slightest environmental impacts (Godfray et al., 2010).

Nutrition might hold the key to the problems mentioned above. The development of knowledge of poultry nutrition and modern biotechnology provide novel nutritional approaches to fit closely the requirement of pullets and laying hens, which will consequently decrease the nutrition excretion and maintain the lower cost of feed. However, birds are more susceptible to diseases, possibly due to the increasingly intensive metabolism for egg formation or weakened immune systems (Cherian, 2013), which makes it imperative to shift the focus to the health-maintenance effect of dietary nutrients. Thus, nutritional approaches aim at fully exerting the genetic potential on production with the priority of maintaining birds' health. In addition, consumer awareness should be considered in modern poultry production, and improving

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the quality of eggs is one of the major points of concern in this area. Egg quality is well known to be influenced by certain nutrients and dietary feed formulation. And insufficient or excessive nutrients in feed are responsible for poor-quality eggs. Nutritional approaches aiming to minimize the incidence of egg defects have been developed. Moreover, nutrients could successfully enrich the egg in some minor components of interest for human nutrition, and by this way the nutritional quality of eggs could be increased. With production of eggs with multiple beneficial properties, nutritional strategies have achieved success in providing a choice of lifestyle to enhance health and to increase psychological well-being.

This paper reviews the nutrient requirements of pullets and laying hens, nutritional modulation of egg quality and hens' health, and provides a useful reference for the study of nutrition strategies and sustainable development of laying hen production.

2. Nutrient requirements of pullets and laying hens

Laying hen nutrition can be precisely divided in various ways according to the demand of phase feeding and the characteristics of birds at different production periods. It is obvious that the onset of lay is the determining turning point of laying hen nutrition, because the biological characteristics and the production purpose of these 2 phases are totally different: for pullets, the aim of nutrition is to build the solid basis for the future production, and can be detailed as guaranteeing the least mortality, optimum health status, proper sexual mature time, and controllable flock uniformity; whereas for laying hens, it is for optimized performance, most prolonged peak period, and optimum immune functions. Accordingly, the studies and recommendations for these 2 phases are significantly different.

Pullet stage is the most rapid growing period of the hen's whole life. Birds at this period have polytropic developmental features, which demand the requirement parameters to be changing correspondingly. NRC (1994) divided the growing phase of pullets into 4 stages by age, i.e., 0 to 6 wk, 6 to 12 wk, 12 to 18 wk, and 18 wk to the age at the first egg. Nevertheless, different countries and enterprises have their own standards in time division. For example, Chinese Feeding Standard of Chicken (Ministry of Agriculture of the People's Republic of China, 2004) recommends a strategy of 0 to 8 wk, 9 to 18 wk, and 19 wk to onset of lay. In the initial post-hatch phase, newly-hatched chicks can utilize the nutrients from the yolk sac for 72 h (Noy et al., 1996), and afterwards shift to entirely exogenous nutrient ingestion. Thus, in this period, the quality of the feedstuffs is of great importance. Dietary energy level is not the first determining factor to affect the laying performance (Babiker et al., 2011), but higher energy level can increase the body weight at the onset of lay (Hussein et al., 1996). Although there are some studies showing that high level of dietary apparent metabolizable energy can improve laying performance (Bornstein and Lev, 1982), it is agreed that energy should be considered on the basis of reasonable protein supply, or be dealt with using statistical modeling with protein (Kuhi et al., 2012). Physiologically, internal organs, bones and muscles grow rapidly in the pullet phase, thus, pullet diets should firstly provide adequate high quality protein to meet the need of the pullets, thus, protein is the most important factor determining the quality of pullet diet. Leeson et al. (1998) reported that, even though the ratios among the essential amino acids (EAA) were kept unchanged, lowered dietary protein can decrease BW of pullet at the age of the first egg. Thus, dietary protein, for content or for sources, is considered prior to all the other ingredients. Besides, to guarantee the utilization of dietary protein, the balance of amino acids must be considered as a priority. However, with the development of laying hen genetics and breeding and the demand of animal health, these data need to be updated. Song (2014) suggested that the requirement of methionine of Jing Brown pullets should be 0.49%, 0.42% and 0.29% at the age of 0 to 4 wk, 5 to 8 wk, and 9 to 17 wk, respectively, and similar results were also found on lysine. These values are significantly higher than those given by NRC (1994) and Chinese Feeding Standards of Chicken (Ministry of Agriculture of the People's Republic of China, 2004). In the last 2 decades, requirements of minerals and vitamins for pullets and laying hens were seldom studied. Guo et al. (2008) reported the metabolic alkalosis caused by high dietary calcium content (3.63%) on 5-wk-old pullets. Abdalla et al. (2009) reported that high level of vitamin A (24,000 IU/kg) did not affect the laying performance of young layers at 18 wk of age. Information on mineral and vitamin requirements should also be re-evaluated to satisfy the constantly increasing performance of layers.

As for nutrient requirement of laying hens, it attracts increasing interests to consider the interaction of different nutrients, rather than consider them individually. Undoubtedly, the interaction of dietary protein and energy and the ratio of various AA still hold the central positions in this field. The study of Panda et al. (2012) on Dahlem Red laying hen showed the optimum requirement combination of 2,795 kcal/kg ME, 16% CP, 0.8% lysine, and 0.4% methionine during 28 to 40 wk of age. Hassan et al. (2013) presented a similar optimum combination with 2,750 kcal/kg ME and 16.0% CP. The balance of dietary energy and protein is universally recognized to be even more important than either one of them alone. In recent decades, these kinds of data are still emerging in large numbers. The interaction of AA (Novak et al., 2004; Figueiredo et al., 2012), the relation between AA and trace mineral (Neto et al., 2011), and calcium and phosphorus were also reported. These observations may definitely help establish more refined database that will more fully tap the potential of the birds.

3. Nutritional modulation of pullets and laying hens

3.1. Nutritional modulation of laying hens' health

In recent years, more and more nutritionists are exploring nutrients' additional benefits such as health-promoting effects rather than their traditional values. Laying hens possess intensive metabolism for the formulation of eggs, thus, they may be more sensitive to adverse circumstances, which, might not be apparent. However, to guarantee the health of birds and consequently egg quality, special attention should be paid to the nutrients in maintaining reasonable immune functions. Antioxidants are a good example, and have long been used to alleviate oxidant stress to maintain health of laying hens in production. The most commonly used ingredients include vitamins E and C (Puthpongsiriporn et al., 2001), and trace minerals like Zn, Cu, Mn and Se (Bulbul et al., 2008). Hosseini (2007) reported that antioxidant nutrients in the diet (i.e., vitamin C 200 mg/kg) can strengthen the immune response of laying hens against heat stress and increase egg quality. Bollengier-Lee et al. (1998) and Çiftçi et al. (2005) reported that dietary supplemented with 500 mg/kg vitamin E or 125 mg/kg vitamin E + 200 mg/kg vitamin C, can improve laying performance and egg quality for laying hens exposed to heat stress. All the dosages applied in these studies are far higher than ordinary nutrient recommendations. These observations imply that the recommendations of vitamins and other trace nutrients with complicated bioactivities should be re-reviewed.

Inclusion of some plants or plant extracts into hen's diet, such as resveratrol (Sahin et al., 2010), ginger root (Zhao et al., 2011), aqueous alfalfa (Deng et al., 2012) have also been reported to improve antioxidant status of laying hens. Much attention has been given to the exploration of new alternative antioxidants, evaluation

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