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The relationship between dietary fat sources and immune response in poultry and pigs: An updated review

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ABSTRACT

The aim of this review paper is to present and discuss the current experimental findings describing the effects of dietary oils on the functions of immune cells and the efficacy of different mechanisms of the immune system in poultry and pigs. The majority of experiments of this kind have focussed on dietary sources of n-3 polyunsaturated long-chain fatty acids (n-3 PUFAs). Their results have shown a significant association between dietary fat (i.e., the level of n-3 PUFAs as well as n-6:n-3 PUFAs ratio in the diet) and different mechanisms of immune response. Dietary supplementation with rich sources of n-3 PUFAs, especially with fish oil, can have a beneficial, modulating influence on the immune system; specifically they appear to decrease acute and chronic inflammatory immune reactions and simultaneously to improve indices of specific immune response. However, several studies demonstrated that anti-inflammatory properties of n-3 PUFAs do not always result in improvement of growth or egg performance.

Contents

1. Introduction

Effective functioning of the immune system is important for protection against infectious diseases, which can negatively affect the production performance and welfare of livestock animals. However, there is some experimental evidence that long-term selection for improved performance (i.e., superior growth rate, carcass weight, and other production traits), may be accompanied by negative physiological consequences, for instance by disadvantageous changes in immune functions and lower resistance of animals to pathogenic factors (Qureshi and Havenstein, 1994; Li et al., 1999; Kramer et al., 2003; Huff et al., 2005; Genovese et al., 2006). For example, in comparing the immunocompetence of fast-growing commercial broilers (Ross 308) and a line of chickens unselected over decades, it was found that long-term genetic selection for increased growth performance adversely affected the adaptive arm of immune response, i.e., antibody production against sheep red blood cells (SRBC) and lymphoid organ relative weights (Cheema et al., 2003). At the same time, such selection enhanced cell-mediated and inflammatory responses (phytohemagglutinin-P (PHA-P)-induced toe-web swelling response and numbers of inflammatory exudate cells) that are less effective for bacterial diseases and often unfavourable for feed consumption, muscle protein accretion and growth performance (Cheema et al., 2003). Meta-analysis of results from different poultry trials has shown that selection for rapid growth performance significantly reduces responses to a variety of immune challenges and may

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have adverse effects on immune functions (van der Most et al., 2011).

Because the nutritional cost of immune functions is relatively high, adequate nutrition is an important factor for the development and effective work of the immune system. Animal requirement for several nutrients, such as certain amino acids, minerals, and vitamins, in order to obtain optimal immune function may be higher than those required for the achievement of maximal growth performance or feed efficiency (Rama Rao et al., 2003; Biswas et al., 2006; Jankowski et al., 2014). However, adding excessive amounts of specific nutrients does not always improve animals' immune response (Klasing, 2007). In recent years, interest in the use of feed components or feed additives with immunomodulatory properties has increased significantly, especially in conditions of intensive poultry and pig production, where many stressful factors have an adverse effect on animal metabolic status and health (Gallois et al., 2009; El Enshasy and Hatti-Kaul, 2013; Darabighane and Nahashon, 2014). Nutritional immunomodulation can be defined as diet supplementation with specific nutrients or feed additives to influence certain aspects of immune function in order to achieve a given goal (Korver, 2012), i.e., efficient functioning of the immune system and resistance to infectious challenges such as viral, bacterial, or protozoan pathogens.

The use of certain dietary sources of fatty acids in animal nutrition is not only a well-documented method for the production of functional food enriched with high contents of n-3 polyunsaturated long-chain fatty acids (n-3 PUFAs) (Pietras and Orczewska-Dudek, 2013; Yanovych et al., 2013; Zdunczyk and Jankowski, 2013), but can also be one of the most efficient nutritional methods of immune-function modulation (Calder, 2001). The effects of dietary fatty acids on immunity are probably due to their importance in a variety of molecular mechanisms, for instance in the synthesis of eicosanoids and cytokines (i.e., mediators of inflammatory response), as well as in T lymphocyte signalling pathways by altering the molecular composition of lipid rafts (Calder, 1998; Miles and Calder, 1998; Calder, 2003; Stulnig, 2003; Stulnig and Zeyda, 2004; Fritsche, 2006; Komprda, 2012; Bederska-Łojewska et al., 2013). A proper n-6:n-3 PUFAs balance in the diet may be important for optimal functioning of the immune system. It should be especially stressed that too high a n-6:n-3 PUFA ratio, often observed in livestock diets, can lead to an increase in the production of pro-inflammatory mediators (cytokines) such as tumour necrosis factor α (TNF), interleukin-1 (IL-1), and interleukin-6 (IL-6) and thus excessively enhance inflammatory response (Simopoulos, 2002), which can negatively affect feed intake (Klasing, 1988; Ferket and Gernat, 2006). Accordingly, the aim of this review paper is to present and discuss the results of recent studies on poultry and pigs evaluating the immune response of animals fed diets supplemented with different fat sources, i.e., oils containing different proportions of n-3 and n-6 fatty acids. As well, the potential for improving production indices in animals as a result of immunomodulation through dietary sources of n-3 PUFAs is discussed.

2. Results of studies on the effects of dietary fats on immunity

2.1. Poultry experiments

Several studies in poultry evaluating the effect of dietary oils with different concentrations of n-3 PUFAs (Table 1) have shown positive responses on the modulation of immune response in order to reduce inflammation, enhance health status, and increase growth performance or egg performance (Tables 2 and 3). The goal of early studies by Fritsche et al. (1991a, 1991b) and Fritsche and Cassity (1992) was to compare the immune functions of chickens fed diets containing different fat sources. The fatty acid composition of immune organs clearly reflected the composition of the dietary fat used (Fritsche et al., 1991b). The authors found that humoral immune response was significantly more efficient (i.e., antibody titres against SRBC were higher) when birds were fed a diet containing a high level of very long chain n-3 PUFAs source (7% fish oil), as opposed to other examined dietary fat sources (lard, maize oil, canola oil, linseed oil). At the same time, proliferative responses to concanavalin A and pokeweed mitogen were significantly lower, and eicosanoid production by isolated immune cells was reduced, in chicks fed diets containing oils rich in n-3 PUFAs (Fritsche et al., 1991a; Fritsche and Cassity, 1992). Selvaraj and Cherian (2004a) showed increased anti-bovine serum albumin (BSA) immunoglobulin concentrations in blood, as well as reduced delayed-type hypersensitivity response, measured as the swelling reaction of the wing web skin to *M. butyricum* antigen, in broiler chickens fed diets containing rich n-3 PUFAs sources (linseed or fish oil). This modulating influence of oils rich in n-3 PUFAs was due to reduced synthesis of pro-inflammatory cytokines and reduced antigen-presenting cell activity, and was positively reflected, at least in the case of fish oil, in feed intake and body weight gains (Selvaraj and Cherian, 2004a). Similar positive changes in immune response were observed by these same authors in laying hens fed diets containing rapeseed and linseed or fish oil; however, these effects were not reflected in feed intake (Selvaraj and Cherian, 2004b). Similar results indicating a modulating effect of n-3 PUFAs on inflammation and immune response were also reported by Wang et al. (2000), who demonstrated that laying hens fed dietary linseed or menhaden fish oil had reduced splenocyte proliferative response to ConA, as well as increased the proportion of IgM+ lymphocytes in the spleen and the concentration of serum IgG, compared to hens fed animal fat or sunflower oil. Similarly, Puthpongsiriporn and Scheideler (2005) reported that a low dietary ratio of linoleic to linolenic acid (n-6:n-3 PUFAs ratio), achieved through supplementation of the diet with linseed oil, increased humoral immune response (i.e., antibody production to Newcastle disease-ND and infectious bursal disease-IBD vaccines), with no effect on growth performance in pullet chicks. In a study with laying hens, Guo et al. (2004) observed higher anti-BSA antibody production and serum lysozyme activity, as well as lower *in vitro* prostaglandin E_2 (PGE_2) production by peripheral blood leucocytes, with no effect on egg performance, when dietary oils rich in n-3 PUFAs (fish oil and linseed oil in comparison to maize oil) were added to the diet for laying hens. The authors indicated that the mechanism of obtained changes in immune response (i.e., enhancement of humoral immunity by n-3 PUFAs, as well as an increase in PGE_2 synthesis and reduction in serum lysozyme activity and antibody production by n-6 PUFAs) were related to modulation of eicosanoid synthesis by dietary oils

Table 1
Approximate composition of common fats used in poultry and pig nutrition.

Fat	Main fatty acids and their approximate content	n-6:n-3 Ratio
Sunflower oil	C18:1–18%, C18:2 n-6–65%, C18:3 n-3–0.5%	130
Maize oil	C16:0–13%, C18:1–32%, C18:2 n-6–45%, C18:3 n-3–1.0%	45
Lard	C16:0–25%, C18:0–14%, C18:1 –42%, C18:2 n-6–10%, C18:3 n-3–0.5%	20
Soybean oil	C18:1–22%, C18:2 n-6–52%, C18:3 n-3–10%	5.2
Rapeseed oil	C18:1–56%, C18:2 n-6–22%, C18:3 n-3–10%	2.2
Flaxseed oil	C18:1–20%, C18:2 n-6–16%, C18:3 n-3–53%	0.30
Fish (menhanden) oil	C16:0–18%, C16:1–11%, C18:1–12%, C18:2 n-6–1.5%, C18:3 n-3–1%, C20:4 n-6–1%, C20:5 n-3–15%, C22:5 n-3–2%, C22:6 n-3–9%,	0.10