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Peroxidized lipids reduce growth performance of poultry and swine: A meta-analysis

Y.T. Hung, A.R. Hanson[1], G.C. Shurson, P.E. Urriola*

Department of Animal Science, University of Minnesota, St. Paul, MN 55108, USA

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ABSTRACT

Animal performance is affected by feeding peroxidized lipids. Nevertheless, inaccuracies and limitations of common lipid peroxidation analyses are associated with inconsistent results regarding animals consuming diets with peroxidized lipids. A comprehensive meta-analysis was conducted to determine the effects of feeding dietary peroxidized lipids on growth performance and oxidative status in poultry and swine. A total of 29 publications with 42 poultry and 23 swine observations were analyzed. Concentration of dietary thiobarbituric acid reactive substances (TBARS) and peroxide value (PV), along with ADG, ADFI, G:F, and serum or plasma concentrations of vitamin E and TBARS were obtained from publications when reported. The relative impact of feeding peroxidized lipids was calculated as a percentage of ADG, ADFI, and G:F relative to responses from feeding isocaloric diets containing unperoxidized lipids. Data were analyzed for outliers, general distribution, and correlations among variables. Overall, feeding peroxidized lipids to both species resulted in a 5% reduction in ADG, a 3% reduction in ADFI, and G:F was reduced by 2% compared with feeding unperoxidized lipids. The difference in the average magnitude of reduction in ADG, compared with less average magnitude of reduction in ADFI, suggests that factors other than caloric intake (i.e. oxidative stress) contribute to reduced ADG when feeding peroxidized lipids. Both species fed peroxidized lipids had reduced serum or plasma vitamin E content (52%) and increased TBARS concentration (120%) relative to animals fed unperoxidized lipids, suggesting that feeding peroxidized lipids contributes to increased oxidative stress. Dietary PV was negatively correlated with ADG ($r = -0.81$, $P < 0.01$) for poultry, whereas for swine, dietary TBARS was negatively correlated with ADG ($r = -0.58$, $P = 0.04$), but there were large prediction errors for poultry (MSE = 0.87) and swine (MSE = 12.79). In conclusion, these results suggest that feeding peroxidized lipids reduce growth performance of poultry and swine, but the magnitude of reduction varies among experiments due to differences in fatty acid profiles among types of lipid sources, time and temperature of peroxidation conditions, and relative growth responses among studies. More accurate peroxidation measurement methods need to be developed to accurately estimate the negative impacts of feeding peroxidized lipids on animal growth performance.

Abbreviations: ADG, average daily gain; ADFI, average daily feed intake; GF, gain feed; DDGS, distillers' dried grains with solubles; AnV, *p*-anisidine value; MDA, malondialdehyde; PV, peroxide value; TBARS, thiobarbituric acid reactive substances; AOCS, American Oil Chemists' Society; 4-HNE, 4-hydroxynonenal; GPx, glutathione peroxidase; CI, confidence interval

* Corresponding author at: 335F AS/VM 1899 Fitch Ave. St. Paul, MN 55108 USA.
E-mail address: urrio001@umn.edu (P.E. Urriola).
[1] Current address: Professional Swine Management, LLC, Carthage, IL 62321, USA.

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1. Introduction

Many sources of lipids are added to poultry and swine diets to increase caloric density, improve palatability and pellet quality, reduce dustiness, and provide essential fatty acids (Azain, 2001; Rocha et al., 2012). However, cost, energy content, and quality vary substantially among lipid sources. Common quality indices used to evaluate lipids include color, fatty acid profile, free fatty acid content, iodine value, saponification value, titer, as well as concentrations of free fatty acids, insoluble, moisture, nonelutable material, total fatty acids, and unsaponifiables (Kerr et al., 2015). While many of these lipid quality measures provide useful information about the characteristics of lipids, they do not directly provide an assessment of the extent of lipid peroxidation. Concentration of unsaturated fatty acids, heat, oxygen, moisture, and pro-oxidant metals affect peroxidation of lipids (Belitz et al., 2009). Dietary lipids are commonly exposed to these pro-oxidant conditions during processing, storage, and extent and time of exposure to these conditions determines the extent of peroxidation (Dibner et al., 2011; Song and Shurson, 2013). During peroxidation, fatty acids are converted into numerous products including peroxides, aldehydes, ketones, acids, esters, hydrocarbons, epoxides, polymers, lactones, furans, and aromatic compounds (Belitz et al., 2009; Rocha et al., 2012; Seppanen and Saari Csallany, 2002; Spiteller et al., 2001).

Several indicative and predictive assays can be conducted to assess lipid peroxidation of various types of lipids, but none of these methods provide a complete assessment of peroxidative damage because numerous and chemically diverse compounds are produced, and subsequently degraded to other compounds during the peroxidation process (Shurson et al., 2015). Among all peroxidation indicator assays available, peroxide value (PV) and thiobarbituric acid reactive substances (TBARS) have been the used because these assays are relatively simple and inexpensive to conduct, but they are inaccurate as single indicators of the extent of peroxidation (Shurson et al., 2015). Despite the limitations of using PV as an accurate peroxidation indicator, some animal nutritionists consider a lipid source to be of inferior quality (rancid) if the PV of a lipid exceeds 20 meq O_2/kg lipid (DeRouchey et al., 2004). Results from an industry survey have shown that the PV of fats and oils can range from 0.1 to 180.8 meq O_2/kg lipid among 610 samples, suggesting large variability in extent of peroxidation among dietary lipids (Dibner, 2013; personal communication). Furthermore, significant amounts of frying oils from restaurants are recycled and directly added to animal feed, or are blended with rendered animal fats to produce animal-vegetable blends (Kerr et al., 2015; van Heugten et al., 2016). Due to prolonged heating of frying oils at high temperatures, they become highly peroxidized and may have PV as high as 248 meq O_2/kg (Rosero et al., 2015).

Because each peroxidation measure provides only partial information of the extent of lipid damage, they have been of limited value in predicting animal growth performance (Kerr et al., 2015). Several studies have shown that feeding peroxidized lipids reduces feed efficiency (McGill et al., 2011a,b; Tavarez et al., 2011), growth rate (Boler et al., 2012; Liu, 2012; Rosero et al., 2015), and energy digestibility (Engberg et al., 1996; Inoue et al., 1984), while increasing oxidative stress (Boler et al., 2012; Liu, 2012), mortality (Anjum et al., 2004; Tahashaki and Akiba, 1999; van Heugten et al., 2016), and impairing immune function (Dibner et al., 1996; Liang et al., 2015; van Heugten et al., 2016). However, these responses, both in direction and magnitude, have not been observed consistently across experiments. Therefore, the objective of this study was to compile and summarize the effects of feeding isocaloric diets containing unperoxidized and peroxidized lipids on growth performance and oxidative status of poultry and swine.

2. Materials and methods

2.1. Data collection and management

Publications with growth performance data from poultry and swine fed peroxidized lipids were obtained by searching online databases (e.g. Agricola, Google Scholar, and Web of Science), scholarly journal archives, and conference proceedings using keywords (i.e. peroxidized lipids; lipid peroxidation; growth performance; broilers; and swine). Additional publications were identified by retrieving citations within many of the published papers. The main criteria for inclusion of data from experiments in this meta-analysis were: (1) animals were fed isocaloric diets containing peroxidized and unperoxidized lipids; and (2) growth performance responses (i.e. gain:feed) were reported regardless of whether the responses were positive or negative.

Twenty six journal articles (Açıkgöz et al., 2011; Anjum et al., 2002, 2004; Bayraktar et al., 2011; Boler et al., 2012; Cabel et al., 1988; DeRouchey et al., 2004; Ehr et al., 2015; Engberg et al., 1996; Hanson et al., 2016; L'Estrange et al., 1966; Liang et al., 2015; Lin et al., 1989; Liu et al., 2014a; McGill et al., 2011a,b; Oldfield et al., 1963; Racanicci et al., 2008; Rocha et al., 2012; Rosero et al., 2015; Tahashaki and Akiba, 1999; Tavarez et al., 2011; Upton et al., 2009; Wang et al., 1997; Yuan et al., 2007; Zhang et al., 2011), 1 abstract (Harrell et al., 2010), and 2 conference proceedings (Inoue et al., 1984; van Heugten et al., 2016) were obtained to provide a total of 29 publications. Some publications evaluated the effects of multiple diets containing peroxidized lipids relative to the effect of similar diets containing unheated lipids. This resulted in 42 comparisons for poultry and 23 for swine. In poultry, 4 comparisons from turkeys were merged into analysis with data from broilers because they included lipids, level of lipid peroxidation, and dietary inclusion rates similar to broiler studies. Sources of dietary lipids included animal fats, vegetable oils, and animal-vegetable blends. Processing temperature and time to induce peroxidation (reported in 82% of the publications (Anjum et al., 2002, 2004; Boler et al., 2012; Cabel et al., 1988; DeRouchey et al., 2004; Ehr et al., 2015; Engberg et al., 1996; Hanson et al., 2016; Harrell et al., 2010; L'Estrange et al., 1966; Liang et al., 2015; Liu et al., 2014a; McGill et al., 2011a,b; Racanicci et al., 2008; Rocha et al., 2012; Rosero et al., 2015; Tahashaki and Akiba, 1999; Tavarez et al., 2011; Upton et al., 2009; van Heugten et al., 2016)) ranged from 27 to 185 °C (mean = 74 °C for poultry experiments and mean = 121 °C for pig experiments) for 7–1968 h (mean = 949 h for poultry experiments and mean = 108 h for pig experiments). Of the 65 comparisons analyzed, 100% reported dietary PV, and 34% reported dietary TBARS concentration among all swine and poultry studies. Both TBARS and *p*-Anisidine value (AnV) assays can be used to estimate concentrations of some secondary lipid peroxidation products, but TBARS is preferred and often used because it is simple, more