Effects of Rapeseed Oil on Production Performance and Egg Quality in Laying Hens and Exploration of Its Mechanism: Postprint

Authors: Yuan Ning, Wang Jianping, Ding Xuemei, Bai Shiping, Zhang Keying

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Abstract

Rapeseed oil is one of China' s important domestically produced vegetable oils, and its erucic acid content is a crucial factor affecting both edible and nutritional value. Laying hens exhibit intense fat metabolism during the laying period, and oil type and level affect their lipid metabolism; furthermore, as oil is a primary component of egg yolk, egg quality is closely related to oil quality and supplementation level in laying hen diets. This article summarizes rapeseed varieties, rapeseed oil classification, and fatty acid composition, focuses on analyzing rapeseed oil' s effects on laying hen production performance and egg quality, and explores its mechanisms by examining its impacts on lipid metabolism, antioxidant capacity, and immunity, aiming to provide a theoretical basis for rapeseed oil application in laying hen production.

Full Text

Effects of Rapeseed Oil on Performance and Egg Quality of Laying Hens and Its Mechanism Exploration

YUAN Ning, WANG Jianping, DING Xuemei, BAI Shiping, ZHANG Keying*

(Institute of Animal Nutrition, Sichuan Agricultural University, Key Laboratory for Animal Disease-Resistance Nutrition of the Ministry of Education, Chengdu 611130, China)

Abstract: Rapeseed oil is one of China' s major domestically-produced vegetable oils, and its erucic acid content is a critical factor influencing both its edible and nutritional value. Laying hens exhibit intensive lipid metabolism

during the egg-laying period, and both the type and level of dietary oils affect their fat metabolism. Since oil is a primary component of egg yolk, the quality and quantity of dietary fat are directly related to egg quality. This article reviews rapeseed varieties, rapeseed oil classifications, and the fatty acid composition of rapeseed oil, with particular emphasis on analyzing its effects on laying hen performance and egg quality. The underlying mechanisms are explored through examining impacts on lipid metabolism, antioxidant capacity, and immune function, aiming to provide a theoretical basis for the scientific application of rapeseed oil in laying hen production.

Keywords: rapeseed oil; egg quality; erucic acid; performance; lipid metabolism

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Rapeseed is the world' s second-largest oil crop, widely cultivated in China, Canada, Europe, India, and Australia. China' s rapeseed planting area and total production account for approximately one-quarter of the global total [1]. Rapeseed oil comprises 42.8% of China's total domestic vegetable oil production, making it one of the country' s primary domestically-produced oils.

Erucic acid content in rapeseed oil is a crucial factor affecting its edible and nutritional value. Numerous studies have investigated the effects of high-erucic-acid rapeseed oil on rats and human physiology. Feeding mice with conventional rapeseed oil containing 32.6% erucic acid significantly increased heart and liver weights, likely due to fat deposition in these organs [2]. Consumption of rapeseed oil with over 10% erucic acid inhibited growth performance and long-chain fatty acid oxidation rates in rat liver tissue, increased erucic acid accumulation in various tissues, and caused myocardial fat metabolism disorders [3-6]. Regular consumption of high-erucic-acid rapeseed oil can lead to myocardial fat deposition and increased blood vessel wall thickness in humans [7]. Furthermore, oil is an essential nutrient for laying hen growth and a major component of egg yolk. Research indicates that changes in dietary fatty acid composition can induce similar changes in egg yolk fatty acid composition. Therefore, although rapeseed varieties have been continuously improved to produce more low-erucic-acid cultivars, high-erucic-acid varieties still exist. Whether high-erucic-acid rapeseed oil increases serum and liver lipid content in laying hens, promotes erucic acid deposition in eggs, and consequently affects egg quality and human health requires comprehensive and in-depth research to enable its scientific and rational application.

1 Rapeseed Oil and Its Fatty Acid Composition

As an edible vegetable oil rich in unsaturated fatty acids, rapeseed oil is indispensable in daily life [8-9]. Monounsaturated fatty acids (MUFA), such as oleic acid, can lower blood pressure [10], reduce inflammation [11], and regulate cholesterol metabolism [12]. Oleic acid is associated with decreased serum total cholesterol and low-density lipoprotein cholesterol (LDL-C) levels and in-

creased high-density lipoprotein cholesterol (HDL-C) levels in individuals with hypercholesterolemia, and can reduce serum glucose levels in diabetic patients [13].

In addition to containing certain amounts of oleic acid, linoleic acid, and linolenic acid [14], rapeseed oil contains a unique fatty acid—erucic acid. Erucic acid constitutes 20%-55% of the fatty acids in cruciferous plant seed oils such as rapeseed oil, but is virtually absent in other vegetable oils [14-15]. Erucic acid is a 22-carbon long-chain fatty acid with one double bond at the 13th position, also known as 13-docosenoic acid, with the molecular formula C22H42O and structural formula CH3-(CH2)7-CH=CH-(CH2)11-COOH (Figure 1 [Figure 1: see original paper]). The physicochemical properties of erucic acid are shown in Table 1 .

Erucic acid content in rapeseed oil varies depending on rapeseed type and cultivar. Generally, *Brassica rapa* (Chinese cabbage type) contains 38%-45% erucic acid, *Brassica napus* (Argentine type) contains 43%-53%, and *Brassica juncea* (mustard type) contains 50%-55% [17]. Rapeseed oil can be classified into general rapeseed oil, low-erucic-acid rapeseed oil, and traditional rapeseed oil based on erucic acid content. In 1996, the Western Canadian Oilseed Crushers' Association (WCOCA) specified that "double-low" rapeseed (Canola) should contain less than 1% erucic acid in the oil and less than 20 mol/g glucosinolates in the meal. China' s national standard GB/T 11762—2006 *Rapeseed* stipulates that double-low rapeseed should contain 3% erucic acid and 35 mol/g glucosinolates, while GB 1536—2004 *Rapeseed Oil* specifies that low-erucic-acid rapeseed oil should contain 3% erucic acid. Rapeseed oil with 3.0%-60.0% erucic acid is collectively termed "general rapeseed oil." Table 2 lists the requirements for some characteristic indicators of rapeseed oil (GB/T 1536—2004). Traditional Chinese rapeseed varieties all contain over 30% erucic acid.

2 Effects of Rapeseed Oil on Laying Hen Performance

The effects of adding rapeseed oil to laying hen diets on performance have been inconsistent. Rowghani et al. [18] found that adding 3% and 5% canola oil to the diet of 24-week-old Hy-Line White laying hens had no significant effect on egg weight. However, Gul et al. [19] reported that adding 2%, 4%, and 6% canola oil to the diet of 40-week-old Hisex Brown laying hens reduced feed intake, laying rate, and egg weight. Faitarone et al. [20] observed no significant effects on feed intake or egg weight when adding different levels of canola oil or soybean oil (2.5%, 5.0%) to Lohmann laying hen diets. Lu et al. [21] found that adding 1%, 2%, and 3% rapeseed oil to the diet of 28-week-old Suqin blue-shell laying hens significantly reduced feed intake but increased egg weight, with no significant effect on laying rate. Vogtmann et al. [22] reported that in peak-laying Leghorn hens, diets containing 5% and 15% conventional rapeseed oil (26.2% erucic acid), low-erucic-acid rapeseed oil (4.1% erucic acid), and soybean oil showed that the 15% conventional rapeseed oil group significantly reduced feed intake and egg weight compared to the 15% low-erucic-acid and 15% soybean oil groups, while

the 15% low-erucic-acid group significantly improved egg weight and yolk weight compared to the 15% conventional rapeseed oil group. These findings indicate that dietary rapeseed oil reduces feed intake in laying hens, but its effects on laying rate and egg weight are inconsistent. Moreover, most research on rapeseed oil' s effects on laying hen performance has focused on different inclusion levels, with minimal reports on the effects of different erucic acid contents—an area warranting further investigation.

3.1 Effects of Rapeseed Oil on Conventional Egg Quality

Current research on rapeseed oil' s effects on egg quality has primarily focused on laying hens, with inconsistent results. Some studies found that adding 2%, 4%, and 6% canola oil to the diet of 40-week-old Hisex Brown laying hens reduced yolk color score and showed a trend toward increased Haugh units [19]. In contrast, Roll et al. [23] found that replacing soybean oil with canola oil in 5-week-old quail diets had no significant effect on egg weight, yolk weight, or Haugh units. Horniakova [24] similarly reported that adding 2% and 6% rapeseed oil to laying hen diets had no significant effect on albumen and yolk weights. However, Rowghani et al. [18] found that adding 5% canola oil to 24-week-old Hy-Line White laying hen diets significantly increased yolk weight, while 3% and 5% canola oil had no significant effect on albumen weight. Lu et al. [21] reported that adding 1%, 2%, and 3% rapeseed oil to 28-week-old Suqin blue-shell laying hen diets increased Haugh units and yolk grade. These results demonstrate that rapeseed oil' s effects on conventional egg quality differ among hen breeds or even within the same breed at different inclusion levels. Furthermore, data on the effects of different erucic acid contents on egg quality and potential residues are lacking and require further research.

3.2 Effects of Rapeseed Oil on Egg Cholesterol and Fatty Acid Composition

The yolk contains over 90% of the cholesterol in an egg. The liver and ovary are the primary organs for cholesterol synthesis in laying hens. The liver receives most of the cholesterol from the blood and assembles it with triglycerides and other components into very-low-density lipoprotein (VLDL) particles in a free form with apolipoproteins. Through endocytosis mediated by the oocyte vitellogenin receptor (OVR), these particles are absorbed by ovarian oocytes, forming 95% of yolk cholesterol and 60% of yolk dry matter. Vitellogenin (VTG), synthesized by the liver, is another source of yolk cholesterol, reaching oocytes through the same pathway to form 4% of yolk cholesterol and 24% of yolk dry matter [25-26].

Research shows that adjusting laying hen diets to alter the ratio of saturated fatty acids (SFA) to unsaturated fatty acids can change yolk fatty acid composition and increase polyunsaturated fatty acid (PUFA) content [27-29]. The lipid portion of egg yolk consists of 8.7 g saturated fatty acids, 13.2 g monounsatu-

rated fatty acids, 3.4 g polyunsaturated fatty acids, and 1.12 mg cholesterol per 100 g fresh yolk [30]. Yolk cholesterol content is influenced by multiple factors including breed, age, rearing conditions, and nutritional level. Adding oils rich in polyunsaturated fatty acids to diets can reduce egg cholesterol content [31]. Lu et al. [21] reported that adding 2% rapeseed oil to laying hen diets resulted in significantly higher yolk cholesterol content than the control group. Rowghani et al. [18] found that adding 3% and 5% canola oil to 24-week-old Hy-Line White laying hen diets significantly increased egg cholesterol content, raising the proportion of linolenic acid in total fatty acids from 1.27% to 3.43% and 6.02%, docosahexaenoic acid (DHA) from 0.15% to 1.31% and 1.47%, and -3 fatty acids in yolk from 1.43% to 4.72% and 6.80%, respectively. Ceylan et al. [32] discovered that adding 1.5% and 3.0% of four different oil sources (sunflower oil, fish oil, flaxseed oil, and rapeseed oil with 2.17% erucic acid) to laying hen diets significantly altered yolk fatty acid composition: higher oil levels increased oleic acid, linolenic acid, and DHA deposition while reducing arachidonic acid deposition; monounsaturated fatty acid deposition decreased with increasing oil levels, while polyunsaturated fatty acid content significantly increased, though cholesterol content remained unchanged. Gul et al. [19] reported that adding 2%, 4%, and 6% canola oil to 40-week-old Hisex Brown laying hen diets significantly increased yolk cholesterol content and elevated oleic acid and total monounsaturated fatty acid content while reducing linoleic acid, -linolenic acid, and total polyunsaturated fatty acid content. Roll et al. [23] showed that replacing soybean oil with canola oil in 5-week-old quail diets changed yolk fatty acid content, significantly increasing oleic acid and monounsaturated fatty acid content while decreasing linoleic acid and polyunsaturated fatty acid content, with no significant effect on yolk cholesterol.

4.1 Effects of Rapeseed Oil on Lipid Metabolism

Dietary oil supplementation affects poultry lipid metabolism and fat deposition, but research on rapeseed oil' s effects on laying hen lipid metabolism is limited. Studies in model animals (rats) have shown that high erucic acid content causes lipid deposition in the liver and heart, increasing their relative weights, while low erucic acid content can alleviate damage from high-fat diets [33-34]. Carroll [35] demonstrated that diets containing 15% erucic acid significantly increased cholesterol accumulation in SD rat kidneys, primarily as cholesteryl erucate, indicating that erucic acid can affect cholesterol metabolism. Zhang et al. [5] found that consuming high-erucic-acid rapeseed oil (47.73%) increased SD rat liver weight in a dose-dependent manner, suggesting erucic acid may be the primary factor causing liver weight gain. Serum triglyceride and total cholesterol levels are commonly used to characterize lipid metabolism status. Gul et al. [19] reported that adding 0%, 2%, 4%, and 6% canola oil to laying hen diets significantly increased hydrocarbon content in serum lipid components, reduced triglyceride content, and decreased cholesterol content in the 6% oil group. VLDL particles assembled with cholesterol and apolipoproteins are also called yolk-targeting VLDL (VLDLy). The primary apolipoproteins synthesized in the

liver are apolipoprotein B100 and apolipoprotein VLDL-II, with the latter covering the surface of apolipoprotein B. Research suggests apolipoprotein VLDL-II may inhibit lipoprotein lipase (LPL) activity [36], while increased apolipoprotein B synthesis in the liver can promote intrahepatic fat transport and reduce fat deposition [37]. After cholesterol synthesis in the liver, it is rapidly transported to the blood as lipoproteins, with most blood cholesterol transferred to egg yolk in VLDL form. Therefore, we hypothesize that different erucic acid contents in rapeseed oil may affect cholesterol and triglyceride metabolism in laying hens, subsequently influencing egg quality. However, current research on the effects of different erucic acid contents on fat deposition in laying hens and the underlying mechanisms is scarce and requires further investigation.

4.2 Effects of Rapeseed Oil on Antioxidant Capacity

Malondialdehyde (MDA) is a lipid peroxidation product formed from unsaturated fatty acid peroxidation and serves as a stable indicator of lipid peroxidation levels, indirectly reflecting cellular damage. Superoxide dismutase (SOD) catalyzes the dismutation of superoxide ions to hydrogen peroxide (H2O2) and is a crucial enzyme defending against superoxide ion damage from internal and external environments. MDA content and SOD activity reflect the intensity of lipid peroxidation and the body' s ability to scavenge oxygen free radicals. Elevated MDA content and reduced SOD activity can trigger oxidative stress responses, leading to cellular damage or death. Reports on rapeseed oil' s effects on antioxidant capacity in laying hens are rare. Rat studies have found that administering rapeseed oil dissolved in 0.5% sodium carboxymethyl cellulose solution at 12.23 mL/kg body weight to male SD rats significantly increased liver SOD activity [38]. Deng et al. [39] reported that high-fat diets significantly decreased serum SOD and glutathione reductase activities in rats, while rapeseed oil feeding increased these activities. Zhang [40] found that SD rats fed high-fat diets had significantly higher MDA content in serum and liver than the basal control group, while the aqueous enzymatic extraction rapeseed oil group had significantly lower liver MDA content than other rapeseed oil groups. These rat studies suggest rapeseed oil can affect antioxidant capacity. Therefore, the effects of different erucic acid contents in rapeseed oil on laying hen performance may be related to its influence on antioxidant capacity.

4.3 Effects of Rapeseed Oil on Immune Function

Fatty acids in oils are primarily classified as saturated, monounsaturated, and polyunsaturated. Nutritional research indicates that fatty acids play important roles in maintaining health [41-43], and dietary long-chain fatty acid composition and content correlate positively with the incidence of various diseases such as tumors, coronary heart disease, and cardiovascular disease [29,44]. Polyunsaturated fatty acids are important components of cell membrane phospholipids. When the body is stimulated by external antigens, lymphokine and antibody secretion and new immune cell production all depend on fat participation. Rape-

seed oil mainly contains polyunsaturated fatty acids such as linoleic and linolenic acids. Researchers have found that linoleic acid significantly improved arthritis symptoms in adjuvant-induced arthritic rats, reduced synovial inflammation, and significantly decreased serum tumor necrosis factor- (TNF-) and interleukin-1 (IL-1) levels [45]. Xia et al. [46] found that 30-week-old Hy-Line Brown laying hens had better immune function when dietary n-3/n-6 ratios ranged from 1:1 to 1:8. Friedman et al. [47] discovered that antibody synthesis ability in chickens initially increased then decreased with increasing dietary linoleic acid levels. Xia et al. [48] showed that feeding laying hens diets containing polyunsaturated fatty acids altered serum lysozyme activity, with fish oil and flaxseed oil groups significantly increasing serum lysozyme activity. Peroxisome proliferator-activated receptors (PPARs) are nuclear hormone receptors and transcription factors that regulate not only lipid metabolism gene expression but also immune and inflammatory responses. Long-chain unsaturated fatty acids (UFA) and their metabolites can activate PPARs [49]. Therefore, dietary fatty acids may mediate immune responses in laying hens through PPARs. Reports on rapeseed oil' s effects on immune function are extremely limited, but differences in fatty acid composition due to varying erucic acid contents may affect immune function, though the specific mechanisms require further investigation.

5 Summary

In summary, rapeseed oil affects laying hen performance and egg quality, likely by influencing lipid metabolism, antioxidant capacity, and immune function—all processes closely related to hen health. Fat synthesized in the liver is transported via blood to adipose tissue for storage and to the ovary for egg production, with dietary fat being the primary source for hepatic fat synthesis. Therefore, rapeseed oil can affect laying hen health by altering dietary fatty acid composition and content. Current egg quality research has primarily focused on conventional egg quality and fatty acid composition, with few reports on erucic acid deposition in egg yolk from high-erucic-acid rapeseed oil diets. While high-erucic-acid rapeseed oil' s effects on lipid metabolism have been extensively studied in rats, research in laying hens is scarce and requires further investigation.

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Note: Figure translations are in progress. See original paper for figures.