

## ALTERNATIVE FEED INGREDIENTS FOR YELLOW CORN AND SOYBEAN MEAL IN POULTRY

Ahmed A. Saleh<sup>1</sup>, Abdullah S. Alawam<sup>2</sup>, Tarek A. Ebeid<sup>3</sup>, Basheer Nusairat<sup>4</sup>, Mohamed S. El-Kholy<sup>5</sup>, Hassan A. Rudayni<sup>2</sup>, Ahmed A. Allam<sup>2</sup>, Mahmoud Alagawany<sup>5\*</sup>

<sup>1</sup>Department of Poultry Production, Faculty of Agriculture, Kafrelsheikh University, 33516 Kafr El-Sheikh, Egypt

<sup>2</sup>Department of Biology, College of Science, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh 11623, Saudi Arabia

<sup>3</sup>Department of Animal and Poultry Production, College of Agriculture and Food, Qassim University, 51452 Buraydah, Saudi Arabia

<sup>4</sup>Department of Animal Production, College of Agriculture, Jordan University of Science and Technology, Ar Ramtha 3030, Irbid, Jordan

<sup>5</sup>Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig 44511, Egypt

\*Corresponding author: dr.mahmoud.alagawany@gmail.com

### Abstract

Due to their useful nutrient availability, soybean meal and yellow corn are frequently utilized as staple components in chicken feed. However, there is a huge demand for these two feedstuffs (yellow corn and soybean meal) from animals. Humanity's numbers are expected to rise to 9.1 billion by 2050. The demand for poultry goods including meat and eggs is rising worldwide. As a result, the demand for poultry feed will rise globally. The supply of wholesome feed for chickens is getting scarcer today. Food security will be at risk, particularly in developing nations. Efforts are being made to replace portions of the most traditional feedstuffs, i.e., soybean meal and yellow corn, with alternate ones. The present review explores the nontraditional alternate feed ingredients which could be included in poultry diets. Moreover, the nutritional value of these alternatives and their bioavailability are explored in this review, alongside means that applied to enhance the nutritional value of these alternatives.

**Key words:** nontraditional feedstuffs, poultry, performance

Due to their high nutrient content, soybean meal and yellow corn are considered the most common traditional feeds in the chicken farming industry. Moreover, they are highly required by farm animals. Poultry items like meat and eggs are being consumed more widely over the world. As a result, there will be a rise in demand for important poultry feeds worldwide, which will raise the price of meat and eggs. According to studies, by the year 2050, there will be 9.1 billion people on the planet (FAO, 2009). Due to the population growth, there will be competition for the available poultry feed ingredients. The demand for poultry products will also rise as the population grows (Alagawany et al., 2022; Attia et al., 2023). Additionally, there is a trend toward using animal feed, especially corn, to meet the growing need for biofuels. This creates yet another significant threat to food security, particularly in poor nations. Currently efforts are being made all over the world to substitute soybean meal and yellow corn with other supplies of protein and energy feedstuffs for monogastric animals like chicken and pigs (Alshelmani et al., 2021; Abd Elghafar et al., 2024). It is common knowledge that several nations produce considerable amounts of non-traditional alternate feed ingredients which include agricultural waste by-products, e.g., wheat and rice bran, cottonseed meal, palm kernel cake, and copra meal (El-Baz and Khidr, 2024; El-Sabroun et al., 2024). However,

such feeds, corn, and soybean contain anti-nutritional components and non-starch polysaccharides (NSPs), including xylan and mannan (Alshelmani et al., 2016; El-Hindawy et al., 2021). NSPs were determined to be the primary cause. Therefore, the aim of this review article is to provide advanced information on non-traditional alternative feed ingredients that can be included in poultry diets. It also explores the chemical composition (Table 1), nutritional value and bioavailability of these alternatives.

### Alternatives of yellow corn

#### *Sorghum*

Globally, sorghum is the fifth most important cereal crop (Hao et al., 2021). Total world sorghum production in 2023 was approximately 60 million tons, but the United States produced approximately 23% of the world's sorghum (Khalifa and Eltahir, 2023). According to McDonald et al. (2010), the staple grain in China, India, and Africa is sorghum. Sorghum's nutritional value is roughly 90–95 percent equivalent to that of yellow corn. Additionally, it costs substantially less internationally than yellow corn (Leeson and Summers, 2005). For crude protein and metabolizable energy, broilers need a large portion of grains in their diets. Sorghum shows a remarkable adaptation in poor soils; thus, it may be grown in low-water locations and in arid climates all over the

world (Gualtieri and Rapaccini, 1990). Apart from tryptophan concentration (0.09–0.12% in sorghum vs. 0.07% in corn), Rama-Rao et al. (1995) observed a comparable amino acid composition between sorghum and corn. Additionally, sorghum's average digestible lysine level is comparable to that of yellow corn.

Sorghum seed serves as a copious source of various phytochemical compounds like phenolic acids, phytosterols, and anthocyanins. According to Awika and Rooney (2004), phytochemical compounds are of great importance in animal health. Additionally, the heightened concentrations of phytochemicals found in sorghum seeds could be partially accountable for their positive effects on human and animal health (Awika and Rooney, 2004). On the other hand, Pour-Reza and Edriss (1997) found that feeding broilers high-tannin sorghum had a horrible impact on performance of the animals. Birds using high-tannin sorghum (1.8%) were found to consume excessive amounts of feed, according to Nyachoti and Atkinson (1995). Such findings contradict those of Attia (1998), who noted little impact on FI in response to sorghum with low tannin (0.22 to 0.50%). Further, Torres et al. (2013) stated that substituting 50% sorghum for corn when feeding broilers did not yield any notable impact on the weights of the muscles and organs. Similar to this, Kumar et al. (2005) claimed that adding specific low tannin pink sorghum stages to broiler diets had no effect on relative yield of carcass and breast muscle. By using sorghum of low tannin content, Nyamambi et al. (2007) found that the digestibility of nutrients (crude protein, ash, and ME) were not affected. Enzymes in the intestinal membrane and epithelial integrity are essential for effective nutrient digestion and absorption from the intestine, including vitamins and amino acids. Therefore, any improvements to the gut mucosa may improve nutrition absorption and digestion (Saleh et al., 2013).

Sorghum contains phytosterols, which have a composition similar to cholesterol and are important for maintaining cardiovascular health in both humans and animals (Fang et al., 2003). Sorghum, in addition, involves flavones and polyflavans, which could be important in lowering LDL cholesterol levels (Krueger et al., 2003). According to Nyamambi et al. (2007), there used to be a sizable negative relationship between the amount of sorghum in broiler diets and plasma lipid levels (total LDL cholesterol and triglycerides). This shows how feeding sorghum grain to birds can change the level of plasma lipids and LDL cholesterol. Sorghum also contains anthocyanins, which have a number of therapeutic benefits, including anti-inflammatory and vasoprotective attributes (Krueger et al., 2003), anti-cancer and chemoprotective attributes (Karaivanova et al., 1990; Alzawqari et al., 2023), and along with anti-neoplastic attributes (Kamei et al., 1995). According to Makled and Afifi (2001), sorghum fed to broilers had little to no influence on the blood GOT and total protein. With the help of sorghum replacements, plasma glucose levels tend to be reduced,

which may also be a result of sorghum's polyphenol content (Krueger et al., 2003). Sorghum feeding may also affect lipid peroxidation by lowering muscle TBARS and MDA levels. According to Jimenez-Ramsey et al. (1994), quails on diets containing sorghum as a replacement for yellow corn increased muscle composition of lipids and ash.

The polyphenols with low-tannin molecular weight of sorghum grains reach and spread through body tissues, potentially exerting an influence on lipid levels. Flavones and polyflavans of sorghum have been demonstrated to possess antioxidant properties (Krueger et al., 2003). According to Ouyang et al. (2016), presence of flavones in broiler chick diets improved their overall antioxidant capacity, GPX, and reduced their blood levels of malondialdehyde. However, the phenolic acids present in low-tannin sorghum, which are typically found as benzoic, caffeic, cinnamic acid, protocatechuic, sinapic derivatives, and p-coumaric acid, demonstrate enhanced antioxidative properties *in vitro*. Consequently, these compounds could contribute to improving health associated with the feeding on whole grains (Adom and Liu, 2002; Omar et al., 2024).

Furthermore, Saleh et al. (2013) discovered a marked enhancement in mRNA expression linked to expansion, antioxidation, and synthesis of fatty acid. Therefore, equal replacing of 50% yellow corn with sorghum (low tannin content) could enhance broiler performance, regulate plasma content of lipids, and improve mRNA expression linked to growth and antioxidation. Ciurescu et al. (2023) investigated the 100% replacement of corn by sorghum and found that the total substitution of corn with sorghum had no negative effects on growth performance, carcass traits and litter quality in broilers.

#### *Wheat bran and wheat middlings*

Wheat Millfeeds (Bran & Midds) are by-products of milling wheat for flour and consist of varying amounts of bran, germ and flour. Wheat bran is highest in fiber and phosphorus and lowest in energy. Wheat middlings (WM) are a by-product of the wheat-milling industry. Middlings comprise coarse and fine particles of bran, shorts, germ, flour, and the offal from the tail of the mill. This product contains the offal and approximately 8 to 9% crude fiber and 30 to 44% NDF (Cromwell et al., 2000). Wheat bran is exported worldwide and is a major feed commodity. However, worldwide production figures are difficult to assess. Wheat production for human consumption (total supply minus wheat produced for animal feeding, seed or wasted) was estimated to be 456 million tons in 2007. When calculated using a bran production rate of 10–19% (see description above), worldwide wheat bran production is comprised between 45 and 90 million tons. The main producers are the main users of milled wheat: China, India, the USA, the Russian Federation, Pakistan, Turkey and France (about 75% of the production) (Heuzé et al., 2020). The outer grain layer of wheat, known as wheat bran (WB), possesses a substan-

tial amount of fiber and a small amount of metabolizable energy (ME), and its use in chicken diets is constrained (Leeson and Summers, 2005).

According to Apprich et al. (2013), the WB is made up of roughly fiber (53%) including xylans, fructans, cellulose, galactan, and lignin, as well as other substances with biological activity (alkylresorcinols, sterols, carotenoids, ferulic acid, flavonoids, and lignans). Additionally, according to Javed et al. (2012), WB contains a high stock of proteins, minerals, vitamins, lignans, bioactive substances, phytic acid, and antioxidants. According to Apprich et al. (2013), WB can be included in poultry rations at levels ranging from 5% to 8% without eliciting any deleterious effects. Through simple steam pelleting, the ME can be increased by up to 10%, and the availability of phosphorus can be increased by up to 20% under the same conditions (Kraler et al., 2014). For intestine fitness, which is considered to control gut microbiota, this by-product should be advised to not exceed 15% in diets (Zimonja et al., 2007). The WB contains xylan, which may potentially cause the small intestine to become more viscous. For broilers receiving a diet that contains more than 15% WB, xylanase supplementation is advised (Leeson and Summers, 2005).

According to Laudadio and Tufarelli (2012), flour represents 70%–75% of the wheat grain, while the left amount (25%–30%) is by-products that can be utilized to feed hens and other farm animals. These by-products are commonly referred to as WM, mill feed (MF), and wheat mill run (WMR), with minimal consideration given to the variety of mill systems that influence their nutritional composition. According to Ahmadi and Amini (2014), the nutritional contents of WM consist of 2,540 Kcal ME/kg, 16% CP, 3.5% EE, 2.7% CF, 0.25% methionine, and 0.55% lysine. Additionally, the starch gelatinization approach is used to address the second cause (Zimonja et al., 2007; Yu et al., 2021). According to Tufarelli et al. (2011), broiler performance could be increased by feeding them 4% of WM. Additionally, Ahmadi and Amini (2014) reported that the incorporation of WM in broilers' diets yielded negligible impact on final live weight, weight gain, feed utilization. On the other hand, Gheisari et al. (2003) claimed that using WM at 30% tiers in the weight loss program for broiler chicks is feasible, barring any unfavorable effects on their performance. Additionally, by feeding 10% of WM, performance was increased because WM contains elevated levels of protein and amino acids, and its fiber content could also pose a risk for the production of enzymes and increase digestibility (Gheisarie et al., 2003; El-Gendy et al., 2023).

Additionally, eating whole grains including WM, barley, and oat lowered blood plasma content of LDL cholesterol that contributed to a 20%–25% reduction in the risk of CVD (Jensen et al., 2006). According to Kristensen et al. (2012), WM are rich in minerals, vitamins, phytochemicals, and fiber, particularly viscous fibers like  $\beta$ -glucans that are responsible for lowering LDL and increasing unsaturated fatty acids in blood plasma.

Additionally, consumption of whole grain has a diminishing effect on synthesis of LDL (Saleh et al., 2019 a; Wang et al., 2006).

However, limited literature exists regarding the utilization of fiber in layer diets over the course of the manufacturing length (Yao et al., 2007; Andersson et al., 2014; Soumeh et al., 2019; Ping et al., 2020). Various experiments have involved the dietary utilization of fiber sources, like WB, rice bran, and sunflower seed meal in both broilers and developing laying hens' diets. Furthermore, modern chicken meals contain ingredients that are high in protein and/or power but often have an excessive amount of bulk density. As a consequence, the addition of 50 kg of WM to a weight reduction program upgraded pellets' quality, and the WM exhibited desirable impacts on the performance, vitamin digestibility, lipid peroxidation, and muscle composition of fatty acids.

#### *Corn silk meal*

Corn silk (*Maydis stigma*) is a by-product of the corn cultivation (Bai et al., 2010). Corn silk is composed of stigma which is yellowish thread-like structures, and is derived from the female flower corn (Alam, 2011). Corn contributes 10% of total food grain in India and corn has numerous industrial applications involved in the production of starch, protein, sweeteners, extruded products, textile, gum, pharmaceuticals, and paper. The major by-product obtained after corn processing is corn silk which is collected around 123–283 kg/ha, and it is conventionally used as agricultural waste, manure or used as animal feed due to lack of effective utilization (Singh et al., 2023). According to Haldar et al. (2019), the CS meal (CSM) originated from beneath the husk of corn grains and is utilized as herbal therapy for bettering human fitness. According to several studies (Hu and Deng, 2011; Ren et al., 2013; Rahman and Wan Rosli, 2014), the beneficial effects of CSM are related to the presence of flavonoids, volatile oils, phytosterols, steroids, alkaloids, saponin, allantoin, and tannins, in addition to minerals (Na, Ca, K, Fe, Zn, and Cl), and vitamins (E and K). As a consequence of its antibacterial (Prajapati et al., 2009), anti-allergic, antiviral, anti-inflammatory (Alam, 2011), anti-hyperlipidemic (Kaup et al., 2011), and anti-diabetic properties (Zhao et al., 2012), CS possesses the ability to serve as an antioxidant and contribute to improve health and wellbeing (Liu et al., 2011). Concerning this matter, incorporating hens' diets with 15% CSM could potentially contribute to the reduction of production expenses, enhancement of health status, and augmentation of performance of broilers (Kirrella et al., 2021). The major concern related to its addition to poultry feeds is its high content of crude fiber (9.5%), which has demonstrated detrimental effects on the efficacy of nutrient utilization and subsequently, productive performance (Ren et al., 2013). The enhancement in performance due to dietary addition of CS could be attributed to its nutrient composition of carbohydrates, crude protein, vitamins and minerals (Hasanudin et al., 2012). Furthermore, results con-

firmed better performance by incorporating 4% and 8% CS in broiler diets, supporting the previous findings (Kirella et al., 2021). Recently, Boeira et al. (2022) showed that CS can be used as a herbal antioxidant ingredient due to its content of bioactive compounds that possess both antioxidant and antibacterial properties. Additionally, the dietary intake of CSM (9% crude protein and 2500 kcal/kg metabolizable energy) led to an improvement in intestinal morphometrical points necessary for efficient nutrient digestion and absorption, which in turn increased overall performance and antioxidative potential (Nessa et al., 2012). The findings are consistent with relevant studies that discussed the probable importance of CSM in bettering the wellness of certain mammals and avian (Arafa et al., 2012).

#### *Olive cake meal (OCM)*

Olive cake (*Olea europaea* L.), a solid by-product of olive oil extraction composed of a mixture of skins, pulp, woody endocarps and seeds (Dal Bosco et al., 2007) is available in large quantities in producing countries. The quantity of oil olives produced in the 2014/2015 crop was 420 000 tons, and Dal Bosco et al. (2007) reported that olive cake represents 35% of the weight of olives pressed. Thus, olive cake produced during one year was around 147 000 tons. The by-product of olive oil extraction known as olive cake meal (OCM) is used in poultry feed. But because some oil cannot be extracted using current technologies from the seeds, this waste is valuable because it contains fat. The OCM has an abundance of oil and can be exploited as a source of antioxidant chemicals (Pappas et al., 2019). Additionally, one of the most significant challenges to OCM is the unpredictability of its chemical makeup (Yanez et al., 2004). In addition, the OCM contains too many lignins. Its usage in rooster feed is constrained since it involves xyloglucan, a non-starch polysaccharide that has been reported to have anti-nutritional impacts on monogastric animals like chicken (Abd El-Moneim and Sabic, 2019). In addition, the presence of protein and carbs combined in feed with considerable quantities of anti-nutritional phenolic compounds such as tannins can potentially restrict the bioavailability of nutrients by inhibiting digestive enzymes (Garcia et al., 2003; Saleh et al., 2019 a). The elevated levels of moisture and fat in OCM are another disadvantage, which poses challenges in terms of both consumption and storage (Chiofalo et al., 2004). However, some processing techniques utilized in the extraction of olive oil (such as those utilizing cutting-edge technologies like microwave, pulsed electric powered field, and ultrasound) could also enhance the OCM digestibility and lead to a decrease in such anti-nutritional constituents (Saleh et al., 2020 a).

Along with the presence of non-starch polysaccharide (NSPs) at elevated level, OCM also has an elevated nutrients content (9–10% crude proteins and 13–18% crude fat) (Al-Harathi and Attia, 2016). The OCM also contains considerable levels of vitamin E, and minerals like Ca, Fe, K, Mn, Na, and P (Ozcan et al., 2020). The OCM

possesses a substantial quantity of residual oil, measuring 6.8%, thereby it is considered a potential supplementary energy source. Additionally, the presence of oleic, linoleic, and linolenic acids in the OCM has an impact on the fatty acid (FA) profiles of broiler tissue (Saleh et al., 2020 b). Al-Harathi (2017) and Sateri et al. (2017) recommended the utilization of OCM up to 10% of the total broiler feed. Furthermore, Sayehban et al. (2020) found that adding OCM to broiler diets up to 15% yielded no adverse effects on performance. However, feeding pigeons on diets containing 10% OCM resulted in a good live weight (Al-Harathi and Attia, 2015). Additionally, Sayehban et al. (2016) reported that adding olive pulp by-products in broiler feeds improved carcass yield and relative organ weights in comparison with control group. According to Papadomichelakis et al. (2019), the inclusion of 5–8% dried olive pulp in broiler diet improved meat quality (lower oxidative balance and higher meat color) and augmented live body weight and feed utilization. According to reviews by Saleh et al. (2020 a) and Cayan and Erener (2015), incorporating 4% OCM by-products into hen diets boosted the serum levels of total protein, albumin, HDL, and HDL/LDL ratio which were associated with lower levels of LDL. Therefore, substituting about 4–10% of corn with OCM in broiler diets leads to good performance, decreased stomach fat and plasma cholesterol, and elevated amounts of oleic acid and linolenic acid as monounsaturated and polyunsaturated fatty acids, respectively.

#### **Alternatives of soybean meal**

##### *Cumin seed meal*

Cumin seed meal is the principal by-product that can be obtained from black cumin seed (*Nigella sativa* L.) after the oil is removed from the fruit and represents 70–75% of the fruit weight. It is extensively grown in India, Iran, Egypt, Morocco, China, Indonesia, Japan, Southern Russia, Pakistan and Turkey. Among all these countries Iran produced about 7000 metric tons of cumin seed meal as a by-product of cumin oil extraction factories, annually (Mansoori et al., 2006). Today in Egypt, cumin seed meal is more affordable than wheat bran (WB) as feed ingredient in animal diets. Egypt represents the world's largest exporter of cumin seed (*Cuminum cyminum*). Cumin seeds include 2–4% of unstable oils (Lucchesi et al., 2004), which are mostly a combination of cuminic aldehyde, or cyminal (its main component) (Pradeep et al., 1993), and cymol, also known as cymene. Cumin seeds consist of 6.2% moisture, 17.7–23% protein, 23.8% fat, 9.1% fiber, 35.5% carbs, and 7.7% minerals. Eight of the 18 amino acids were shown to be essential, with tryptophan serving as the initial limiting amino acid (Joe and Lokesh, 1997). Cumin seeds are extremely nutrient-dense; they include large quantities of fatty acids (particularly monounsaturated ones), crude protein, crude fiber, vitamins (particularly B and E), and minerals (particularly Fe) (Bettaieb et al., 2011). There are numerous studies concerning the nutritional importance and thera-

peutic impacts of cumin seed and its oil on humans and animals (Gagandeep et al., 2003), but few studies have been published on its utilization in poultry (Mansoori et al., 2006).

Additionally, cumin seed is frequently employed in conventional medicine for a variety of purposes, e.g., improving digestion, appetite, and immunity (Gilani et al., 2004). It also has antibacterial and antioxidant properties (Bourgou et al., 2012). Thymoquinone, thymohydroquinone, dithymoquinone, and thymol are among the critical pharmacologically energetic components of cumin seed oils, while selenium, all-trans-retinol, and DL-tocopherol are considered to be the more pivotal antioxidants (Al-Saleh et al., 2006). According to Mansoori et al. (2006), dietary inclusion of 2.5 or 5% cumin seed meal in hen diets increased egg weight and FCR but had little effect on body weight or feed consumption. Cumin's digestive-stimulating and antibacterial properties may be responsible for the beneficial effects on performance (Galib and Al-Kassi, 2010). It has been evidenced that the active constituents of cumin boost bile acid function and promote the secretion of digestive enzymes (proteases, amylases, and lipases) (Srinivasan, 2005), which were responsible for lowering liver MDA (an index of lipid peroxidation) and yolk LDL cholesterol content in laying hens (Saleh et al., 2019 b). Additionally, Platel and Srinivasan (2001) stated that the inclusion of cumin in the diets reduced the rate of passage of meal through gastrointestinal tract by 25%, which may have been connected to its positive impact on bile secretion or digestive enzymes. Saleh et al. (2020 b) recently came to the conclusion that replacing wheat bran with 100% cumin seed meal increased productivity (egg number, weight, and mass) and egg quality traits (yolk color, shell thickness, and Haugh unit), and lowered MDA in liver of laying hens. In order to improve laying performance and quality, and decrease lipid peroxidation, cumin seed meal may be fed.

#### *Canola meal*

Rapeseed meal, called canola meal in North America, Australia and some other countries, is the by-product of the extraction of oil from rapeseed (*Brassica napus* L., *Brassica rapa* L. and *Brassica juncea* L., and their crosses). It is a protein-rich ingredient that is widely used to feed all classes of livestock. Worldwide production of rapeseed meal is second only to soybean meal (Doré and Varoquaux, 2006). Global rapeseed meal production was 38.8 million tons in 2018 which is slightly lower than in 2015–2016 (39.1 million tons) (USDA, 2016). In 2018, the main producer of rapeseed meal was the European Union (12.8 million tons), followed by China (9.6 million tons), Canada (5.3 million tons) and India (4.0 million tons) (Heuzé et al., 2020). The canola cultivation is expanding significantly in the western region of Canada as well as in other regions of the world (Leeson and Summers, 2005). The rising demand for canola oil once had an impact on the production of canola. Canola meal is a by-product during the process of extracting oil, and has a

substantially lower lysine level than soybean meal. However, amino acids containing sulfur are more abundant than those in soybean meal. Due to the presence of tannins, senapine, fibers, phytate, and glucosinolates, along with its limited metabolizable value, canola meal is problematic for use in poultry feeds (Ghosh, 2020). The administration of canola meal in laying hen diets has been found to lead to small and fishy taint eggs (Leeson and Summers, 2005). Two techniques currently employed to augment the nutritive value of canola meal are extrusion and fermentation with lactic acid bacteria (Alyileili et al., 2020). Canola meal can therefore be added to chicken diets up to 5–8% (Leeson and Summers, 2005) and can be increased to 10% in broiler diets (Aljubori et al., 2017). However, canola seeds have a high NSP content (Meng et al., 2005). According to a recent study by Chegeni et al. (2011), broiler chicks fed 25% canola seed performed better when combined with  $\beta$ -mannanase, a hemicellulase that contributes to the degradation of NSP. According to Zanini et al. (2006), broilers fed a diet containing canola seed oil experienced an increase in body weight attainment. Unsaturated fatty acids, in particular, are abundant in canola oil. Rahimi et al. (2011) verified that the broiler weight loss plan's use of canola seed caused a decrease in FI. Canola seeds may also reduce the amount of stomach fat pads in broiler chicks (Shahryar et al., 2011). Additionally, feeding probiotics along with canola seeds decreased plasma levels of total LDL cholesterol and triglycerides while increasing plasma levels of HDL cholesterol (Kim et al., 2003; Zanini et al., 2006). These findings suggest that the phytosterols in canola seeds may be responsible for the reduction in total LDL cholesterol caused by canola seed feeding (Ling and Jones, 1995; Bruckert et al., 2010). Additionally, phytosterols in canola seed may compete with dietary and biliary LDL cholesterol for absorption in the brush border and displace LDL cholesterol from bile salt micelles (Ntanios and Jones, 1999). The composition of FAs in the form of increasing unsaturated FAs ( $\alpha$ -linolenic acid) in breast muscle was also improved by feeding canola seeds (Asadi et al., 2011). Therefore, when made on a foundation of digestible amino acids, canola meal has the potential to serve as a viable alternative to SBM in isocaloric feeds without causing any marked effects on live weight, feed consumption, FCR, and mortality rate. Also, soybean meal can be replaced by CM at levels up to 20% of the total diet without affecting carcass yield, composition of meat or the instrumental or sensory characteristics of the meat of broilers (Gopinger et al., 2014).

#### *Peanut (groundnut) meal*

Peanuts, also known as groundnuts, alongside rapeseed, soybean, sunflower seed, and cottonseed, are one of the world's five major oil crops with widespread cultivation and production globally. Peanuts, a type of leguminous plant, are cultivated in tropical and subtropical areas. Their common utilization is to obtain oil from seeds and their by-product (meal) is utilized to provide protein

to animal diets (Sarbaz et al., 2018). According to the data from the website of Statista, peanut oil production is estimated to be around 5.86 million metric tons from 2021 to 2022, accounting for approximately 3.14% of the world's total annual output of edible vegetable oil (Statista, 2023). Based on the FAO's enterprise statistical database, China was the largest peanut producer in 2021, with an output of 18,307,800 tons, followed by India and Nigeria with outputs of 10,244,000 tons and 4,607,669.46 tons, respectively. In 2020, the global production of peanut oil reached 4.61 million tons (FAOSTAT, 2021), which sufficiently illustrates the significance of peanuts in agricultural production and trade (Zhao et al., 2012). The end product of the process of extracting peanut oil is known as peanut meal (PNM). This ingredient contains about 47% CP and 0.5–1% oil. Trypsin inhibitors are a drawback of using PNM in poultry diets. Thankfully, it may be cleansed with the help of warmth therapy during the oil extraction process. Mycotoxins including aflatoxins have detrimental effects on poultry productivity. It is challenging to consider the possible aflatoxin exposure. To solve this issue, sodium-calcium aluminosilicates should be added to the feedstock since they bind to aflatoxin and prevent its absorption (Kana et al., 2013). Because it contains more than one peel and shell remnant and 10% crude fiber, PNM is regarded as fibrous (Davis and Dean, 2016). The residual oil content material is extremely varied because of the thorough extraction processes; it can range from 3% or more for a meal that was extracted using solvent to 10% for cakes that were extracted regularly. Unsaturated fats, principally linoleic and oleic, make up more than 90% of the fats in peanut oil (Bera et al., 2019). Lysine, threonine, and methionine deficiencies are among the challenges associated with using PNM in broiler diets (Zhang and Parsons, 1996). Another issue that restricts the use of PNM in broiler diets is mineral insufficiency. The phytase enzyme, on the other hand, has been found to increase mineral availability, increasing metabolizable energy. It is important to remember that PNM should not be utilized as the only protein source in broiler feeds, however it can be utilized effectively at levels up to 15% in combination with the other dietary sources of protein (Diaw et al., 2010; Ghadge et al., 2009). However, Toomer et al. (2019) stated that, in contrast to the other treatments, feeding excessive oil PNM reduced the weights of the carcass components. However, Sarbaz et al. (2018) found that feeding birds a 5% peanut pod increased carcass weight and decreased stomach fat pad. According to Aito Inoue et al. (2007), the decrease in deposited fat in the abdomen is possibly attributable to the augmentation in n-3 FAs in PNM along with AA stability (lysine in particular) in diets of broilers. Additionally, PNM at 5.3% and 10.6% of the diet decreased the concentration of LDL cholesterol in egg yolks (Lu et al., 2013). According to Bera et al. (2019), the decrease in plasma concentrations of LDL and triglyceride could be attributed to the elevated amounts of unsaturated FAs in PNM. These residues also

help to increase hepatic transformation of LDL by expanding the range of hepatic LDL receptors, which lowers plasma LDL cholesterol levels (Fernandez and West, 2005). PNM possess a high content of phytosterol (Han et al., 2015), which has a chemical construction similar to that cholesterol in animal and contributes to lowering LDL in bloodstream (Abd El-Moneim et al., 2020). Feeding broilers diets containing 10% PNM, in place of corn and soybean meal, had no longer an impact on the metrics measuring their increased overall performance and fitness.

#### *Linseed meal*

Linseed meal is the by-product of oil production from linseeds. In 2020, world production of flax (linseed) was 3.4 million tons, led by Kazakhstan with 31% of the total. Other major producers were Russia, Canada, and China (Allaby et al., 2005). Linseed, an oil crop, has a significant amount of crude protein (25–35%) and an abundance of n-3 FAs. The by-product produced during extracting oil from linseed is known as linseed meal (LSM). Numerous factors, including low methionine and lysine content, excessive fiber content, and anti-nutritional components, prevent the inclusion of LSM in chicken diets in excessive amounts (Iji et al., 2017). Anti-nutritional elements present in LSM, such as cyanogenic glycosides, allergens, phytic acid, anti-pyridoxine, mucilage, and goitrogens, could bind with water molecules, consequently leading to an elevation in digesta viscosity. High-viscosity digesta causes a biofilm to develop on the epithelial layer of the GIT, enhancing fermentation and the spread of harmful bacteria, thus raising the hazard of illnesses, and decreasing the productivity of the livestock (Pirmohammadi et al., 2019). Very few works have researched how feeding LSM affects the meat composition of AA in broiler chicks. It is important to remember that dietary protein plays a vital role in supplying the essential AA, which are needed for maintaining basic physiological characteristics, repairing damaged tissues, and growing muscles (Toomer et al., 2020). The diets can be made with plant or animal protein sources; however, broiler diets commonly incorporate plant-based feedstuffs because of their accessibility and affordability (Babatunde et al., 2021). The conflicting results of earlier research may be related to dietary inclusion levels, chemical composition, oil percentages, and the amounts of anti-nutritional components in each item (Mridula et al., 2011). Levels of n-3 FAs in meat yield were increased, which concerned lowering lipid peroxidation and improving the humoral immune response in Japanese quail, according to Mridula et al. (2011), who also noted that the increase in growth performance of broilers was no longer impacted in response to including LSM in feed at the level of 10% (Ebeid et al., 2011). Further, Meherunnisa et al. (2017) found that, excluding any negative effects, water-treated LSM could be incorporated in broiler chick feeds up to 15%. Additionally, in order to overcome the AA deficiencies such as threonine, adding threonine (0.10%) to broiler chick

diets containing LSM caused higher live weight and feed utilization than control, however, there were no significant changes observed in relative weights of carcass parts (Costa et al., 2001). Pekel et al. (2009) stated that broilers given flaxseed-based diets (10% from hatch to 21 d of age) undergo considerable alterations in relative weights of carcass and breast. Additionally, earlier studies had shown that the LSM might result in viscous digestion, inhibit reutilization of bile salts, and disrupt digestion lipids, all of which would lower serum levels of LDL cholesterol and triglycerides (Kristensen et al., 2013). Additionally, eating soluble fiber could decrease blood stream content of TC and LDL as well as triglycerides by enhancing the excretion of bile salts in the feces (Maki et al., 1999). Therefore, feeding broilers diets with 100 kg/ton LSM as a replacement for soybean meal had no effect on the measures relating to their increased performance and fitness reputation.

Table 1. Chemical composition of the ingredients

|                 | Crude protein (%) | Metabolizable energy (kcal/kg) | Crude fiber (%) | Fat (%) | Calcium (%) |
|-----------------|-------------------|--------------------------------|-----------------|---------|-------------|
| Sorghum         | 8.7               | 3345                           | 2.32            | 3.01    | 0.051       |
| Wheat bran      | 15                | 1340                           | 6.3             | 4.2     | 0.15        |
| Wheat middlings | 16                | 2540                           | 2.7             | 3.5     | 0.07        |
| Corn silk meal  | 12.51             | 2550                           | 9.5             | 2.23    | 0.31        |
| Olive cake meal | 8.2               | 3675                           | 11.55           | 17.8    | 0.021       |
| Cumin seed meal | 16                | 2900                           | 20.9            | 2.19    | 0.43        |
| Canola meal     | 36.5              | 2050                           | 11.6            | 3.6     | 0.67        |
| Peanut meal     | 23                | 3670                           | 11.4            | 21      | 0.1         |
| Linseed meal    | 36                | 1850                           | 8.5             | 8.7     | 0.2         |
| Poultry fat     | –                 | 9150                           | –               | –       | –           |
| Rice bran oil   | –                 | 8954                           | –               | –       | –           |
| Eggshell meal   | –                 | –                              | –               | –       | 43.16       |

### Alternatives for oil sources

All the aforementioned ingredients (corn, sorghum, cumin seed, soybean, and linseed) involve considerable amounts of fat. Additionally, these ingredients can provide the hen with PUFAs such as omega-3 and omega-6 (Grigorova et al., 2017; Madeira et al., 2017).

### Poultry fat

After various hydrations, filtrations, and degumming processes, soy oil (SO) is the major source of fats utilized in chicken feed composition in the Middle East (Beauregard et al., 1996). However, it is expected to have a limited grant and steadily rising costs. Rendered rooster fats, waste products of rooster abattoirs, could be used as alternatives to SO because of their high bioavailability and incredibly low cost. Additionally, adding PF to the diet offers a variety of advantages on diet texture, palatability, and intestinal absorption by reducing food passage time through the digestive system (Józefiak et al., 2014; Okur, 2020). However, risks associated with using animal fat in poultry diets include spoilage and limited use in young

chick (Aardsma et al., 2017). When 50% PF was utilized in place of SO, no variations in performance metrics were found in the literature (Hu et al., 2019). However, it is important to remember that when animal fats as PF and tallow were coupled with vegetable oils, a synergistic effect was seen (Tufarelli et al., 2015). The PF is typically utilized in feed mills, but the European Union's restrictions and specific rules on such practice have prompted challenges for these establishments within the countries of the European Union (Patra et al., 2011). However, due to the highly nutritive composition of PF, economic considerations, high manufacturing expense, and the exorbitant cost associated with the implementation, these by-products need to be reintroduced into the manufacturing and financial systems (Nayebpor et al., 2007). According to several studies, incorporating vegetable oils in hen diets could enhance productivity and carcass characteristics, along with manufacturing efficacy by raising feed power stage above animal fats (Zampiga et al., 2016). Others hypothesized that hen performance would be improved by a combination of 50% vegetable oils and 50% animal fats (Aardsma et al., 2017). However, some studies found no statistically significant differences between vegetable and animal fats (Pesti et al., 2002). An increase in fat weight was seen in an experiment conducted by Okur (2020) when animal fat was added to broiler diets. The dietary fat sources and panel of FA (particularly the essential ones like linolenic and linoleic FA) have a significant impact on the growth efficiency of broilers because their lack can also slow broiler growth (Józefiak et al., 2014). The balance ratios of energy to protein or to AA in PF-based meals should also be considered when explaining why there were no variations in the poultry performance (Okur, 2020). Furthermore, Pesti et al. (2002) noted that consuming fat sources (feed- and pet food-grade poultry greases, restaurant grease, white grease, animal/vegetable oil blend, palm oil, yellow grease) with an excessive amount of metabolizable energy caused an excessive amount of fat to be deposited. This may provide an explanation for the high abdomen fat of poultry which received meals containing increased amounts of PF. The digestion of nutrients is strongly influenced by the FAs chain size and unsaturated FA to saturated FA ratio (U/S ratio since the low ratio found in certain sources (like tallow and palm oil) have been linked to significantly unfavorable effects on vitamin digestibility (Tanchaoenrat et al., 2014; Viveros et al., 2009). To our knowledge, only a small number of studies have looked at how dietary fat addition affects the blood chemistry of different poultry species. Several of such research (Donaldson et al., 2017) concentrated on the influence of different fat sources on the quality of poultry products intended for human utilization with no consideration for the changes in the fitness repute of birds throughout manufacture. Hu et al. (2019) found that dietary PF had a negligible effect on the serum levels of HDL, LDL, and TC in ducks. In addition, insignificant variations in the blood content of total protein, albumin, and LDL, and activity of AST were ob-

served by Donaldson et al. (2017) in quail that received feeds containing either PF or lard. Data on blood serum content of triglyceride in response to various dietary fat sources and amounts, have been rather conflicting. On the other hand, according to other studies, humans and birds fed excessive dietary lipids had significantly higher serum triglycerides (Kim et al., 2011). While some researchers identified a considerable reduction in its level (Howe et al. 2006), others revealed non-significant modifications (Donaldson et al., 2014). The limit in blood triglycerides, according to Donaldson et al. (2014), may be due to a decrease in the liver's ability to synthesize FAs from scratch, as the birds have been receiving enormous amounts of FAs through their diets. The inconsistent results of these studies suggest that different lipid management pathways and multiple potential mechanisms, such as post-absorption lipid metabolism and liver uptake of HDL, may regulate circulatory levels of LDL and triglycerides in many poultry species. The lipid profile of breast meat is generally improved when PF is added to broiler diets in place of soy oil (Saleh et al., 2021). As anticipated, substituting SO with PF has significantly enhanced the financial effectiveness and benefit-to-cost ratio, depending on the substitution rate. This effect results from the significant disparity between the costs of SO and PF; under the conditions of the unusual study, the cost of SO was once 4.6 times that of PF. Due to the fact that SO is a major fat source in poultry diets and has numerous manufacturing applications, the price differences between SO and PF are reasonable. Although it has a low price, being a by-product of poultry abattoirs, the use of PF is more cost-effective and has less of an adverse impact on the environment. Several studies have demonstrated that using PF instead of SO has financial benefits (Donaldson et al., 2017; Jansen et al., 2015). As a result, feeding PF to broilers can be used to partially or completely replace SO in their diet without harming their general performance or health to upgrade their meat quality.

#### *Rice bran oil*

In comparison to other traditional vegetable oils, rice bran oil (RBO) is very popular because of its high quality, long shelf life, good-balanced FA content, and numerous antioxidant properties (Lai et al., 2019; Punia et al., 2021). Tocopherols, tocotrienols, and other phytoconstituents with biological activity, such as phytosterols, squalene,  $\gamma$ -oryzanol, and triterpene alcohols, are abundant in the RBO (McCaskill and Zhang, 1999). Such substances were recorded to have immune-stimulating, anti-inflammation properties, and hypocholesterolemic activities (Punia et al., 2021). Due to its balanced fatty acid composition, which has a ratio of 1:1.1:0.6 for PUFA, MUFA, and SFAs, respectively (Selim et al., 2021), the RBO is one of the healthier edible oils. The major 3 FAs in RBO are oleic acid (C18:1), linoleic acid (C18:2), and palmitic acid (C16:0), which represent nearly 42, 32, and 20%, respectively, of the total FAs content in RBO (Lai et al., 2019; Punia et al., 2021). Although RBO only contains

a modest amount of linolenic FA, it is adequate for de novo synthesizing of several 3-PUFA in tissue phospholipids, including eicosapentaenoic acid and docosahexaenoic acid (Ali and Devarajan, 2017). Due to its superior FA content along with the bioactive substances, including sterols, oryzanols, polyphenols, tocopherols, tocotrienols, and phenolic acids, the RBO is recognized as amongst the vegetable oils that have most benefits on the health status (Lai et al., 2019; Punia et al., 2021). In humans and animals suffering from hyperlipidemia (Zhang et al., 2020) these biologically active constituents have been found to reduce oxidative stress indicators, TC, and LDL. Furthermore, it has been postulated that RBO may also mitigate the risk factors associated with cardiovascular ailments. Consequently, RBO could serve as a great natural option for supplying broiler diets with PUFA and antioxidants, thereby augmenting productivity, health status, antioxidant potential, and meat quality. Previous studies on broilers fed diets supplemented with 4% RBO found improved performance, prolonged immunological response, and decreased LDL cholesterol (Purushothaman et al., 2005; Kang and Kim, 2016; Zaki et al., 2023). According to Anitha et al. (2006), RBO has significant positive effects on the final LW, WG, and FCR. These effects were more pronounced when it made up to 3% of broilers' diets. Similar results on the improvement of broilers' FCR and LW were obtained using 2% RBO (Baiao and Lara, 2005). However, previous studies found no appreciable differences in FI between the experimental groups (Ayed et al., 2015). The beneficial effects of RBO on broiler performance may also be attributed to its bioactive components (Anitha et al., 2006). The strong energy-producing properties of PUFA may also be responsible for the reduced FI seen here in broilers receiving dietary RBO (Khatun et al., 2017). According to Ahmed et al. (2018), RBO administration suppressed the prolonged liver de novo lipogenesis of the insulin-resistant mice by downregulating the superoxide dismutase and catalase lipogenic genes. As a result, RBO's suppressive effects may also be attributable to its unsaponifiable components, which have also been shown to decrease sterol regulatory element-binding protein-1 (Ham et al., 2016). Thus, these findings proposed that RBO could also affect lipid metabolism in broilers. Additional research is needed to confirm this mechanism, though. At the time of the experimental groups' 24-hour autopsies, the inclusion of RBO in broiler diets did not yield marked effects on the meat lightness ( $L^*$ ), redness ( $a^*$ ), or yellowness ( $b^*$ ) values of both breast and thigh flesh (Turcu et al., 2021). In the same context, Qi et al. (2010) added different oils to a broiler chicken's diet and recorded an impact on the meat's color, and documented a correlation between meat pH and the physicochemical traits, including color and hardness. The breast and thigh muscle mass pH readings in this investigation were within normal pH ranges (Turcu et al., 2021; Abd El-Moneim et al. 2022). These findings concur with those of Jankowski et al. (2012) and Khatun et al. (2018). Inclusion of rice bran (full-fat type) at 6–18% in goose diets had no long-

er an impact on the meat's fine characteristics, such as color and pH (Sun et al., 2016). According to Priolo et al. (2001), meat acidity (pH) is significantly influenced by glycogen, but there were no obvious differences in color of abdomen fat in broiler chicks. This is likely because RBO contains very little beta-carotene, lutein, and zeaxanthin (Lamberts and Delcour, 2008). As a result, RBO may be employed as a prized environmentally friendly element in broiler chicken feeds to boost immune function and performance, improve blood lipid profiles, hepatic function, and antioxidant status, and augment the nutritional content of the products.

### Conclusions

Yellow corn and soybean meal are conventional feed ingredients used as the main feedstuffs in poultry feeds be-

cause of their high nutrients availability. Currently, great efforts are being made worldwide to replace soybean meal and yellow corn with other protein- and energy-rich feeds for monogastric animals. The use of alternative feed ingredients nowadays in poultry industry is going to be increased due to their nutritive quality and as a cheap source of energy and protein. Furthermore, these alternatives such as sorghum, wheat bran and wheat middlings, corn silk meal, olive cake meal, cumin seed meal, canola meal, peanut (groundnut) meal, linseed meal, poultry fat and rice bran oil are not competitive with human nutrition. At the same time, their incorporation into poultry diets has the potential to partially substitute soybean meal and yellow corn, and this would result in a reduction in production costs. Feed ingredients and alternatives of soybean meal in poultry diets were summarized in Table 2.

Table 2. Feed ingredients and alternatives of soybean meal in poultry diets

| Ingredient            | Level (%)                          | Results                                                                                                                                                                                              | Reference                                         |
|-----------------------|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| 1                     | 2                                  | 3                                                                                                                                                                                                    | 4                                                 |
| Sorghum               | Substituting 50% sorghum for maize | Did not yield any notable impact on the weights of the muscles and organs                                                                                                                            | Torres et al. (2013)                              |
| Sorghum               | 50% yellow maize with sorghum      | Could enhance broiler performance, regulate plasma content of lipids, and improve mRNA expression linked to growth and antioxidation                                                                 | Saleh et al. (2013)                               |
| Wheat bran            | 15% wheat bran                     | Xylanase supplementation is advised in broiler diets                                                                                                                                                 | Leeson and Summers (2005)                         |
| Wheat bran            | 15% wheat bran                     | Should be advised to not exceed 15% in diets                                                                                                                                                         | Zimonja et al. (2007)                             |
| Wheat middlings (WM)  | 4% of WM                           | Broiler performance could be increased with this level                                                                                                                                               | Tufarelli et al. (2011)                           |
| Wheat middlings       | 10% of WM                          | Performance was increased because WM contain elevated levels of protein and amino acids                                                                                                              | Gheisarie et al. (2003); El-Gendy et al. (2023)   |
| Corn silk meal (CSM)  | 15% CSM                            | Incorporating hens' diets with CSM could potentially contribute to the reduction of production expenses, enhancement of health status                                                                | Kirrella et al. (2021)                            |
| Corn silk meal        | 4% and 8% CS                       | Incorporating CS in broiler diets, supporting the previous findings                                                                                                                                  | Kirrella et al. (2021)                            |
| Olive cake meal (OCM) | 15%                                | Adding OCM to broiler diets up to 15% g yielded no adverse effects on performance.                                                                                                                   | Sayehban et al. (2020)                            |
| Olive cake meal       | 10% OCM                            | Feeding pigeons on diets containing OCM resulted in a good live weight                                                                                                                               | Al-Harthi and Attia (2015)                        |
| Olive cake meal       | 4%                                 | Incorporating OCM by-products into hen diets boosted the serum levels of total protein, albumin, HDL, and HDL/LDL ratio which was associated with lower levels of LDL.                               | Cayan and Erener (2015)                           |
| Cumin seed meal       | 2.5 or 5 %                         | Dietary inclusion of cumin seed meal in hen diets increased egg weight and FCR but had little effect on body weight or feed consumption                                                              | Mansoori et al. (2006)                            |
| Canola meal (CM)      | 5–10%                              | Canola meal can therefore be added to chicken diets up to 5–8% and can be increased to 10% in broiler diets                                                                                          | Leeson and Summers (2005); Aljubori et al. (2017) |
| Canola meal           | 20%                                | Soybean meal can be replaced by CM at levels up to 20% of the total diet without affecting carcass yield, composition of meat or the instrumental or sensory characteristics of the meat of broilers | Gopinger et al. (2014)                            |

Table 2 – contd.

| 1                        | 2                             | 3                                                                                                                   | 4                                                                    |
|--------------------------|-------------------------------|---------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Peanut (ground-nut) meal | 5–15%                         | Feeding birds a 5% peanut pod increased carcass weight and decreased stomach fat pad                                | Sarbaz et al. (2018); Diaw et al. (2010); Ghadge et al. (2009)       |
| Linseed meal             | 10% from hatch to 21 d of age | Increased relative weights of carcass and breast in broiler chickens                                                | Pekel et al. (2009)                                                  |
| Poultry fat              | 50% PF                        | When 50% PF was utilized in place of soybean oil, no variations in performance metrics were found in the literature | Hu et al. (2019)                                                     |
| Rice bran oil            | 4%                            | Improved boom performance, prolonged immunological response, and decreased LDL cholesterol in broilers              | Purushothaman et al. (2005); Kang and Kim (2016); Zaki et al. (2023) |

### Acknowledgements

This work was supported and funded by the Deanship of Scientific Research at Imam Mohammad Ibn Saud Islamic University (IMSIU) (grant number IMSIU-DDR-SP2501).

### Conflict of interest

None.

### References

- Aardsma M., Mitchell R., Parsons C. (2017). Relative metabolizable energy values for fats and oils in young broilers and adult roosters. *Poult. Sci.*, 96: 2320–2329.
- Abd Elghafar R., Abaza M., Ellakany H.F., Abd El-Hady A.M., El-Sabrou K. (2024). The effect of fermented wheat germ extract on broiler chicks' growth performance, immunological status, and carcass characteristics. *Ann. Anim. Sci.*, 24: 1323–1331.
- Abd El-Moneim A.E., Sabic E.M. (2019). Beneficial effect of feeding olive pulp and *Aspergillus awamori* on productive performance, egg quality, serum/yolk cholesterol and oxidative status in laying Japanese quails. *J. Anim. Feed Sci.*, 28: 52–61.
- Abd El-Moneim A.E., Selim D.A., Basuony H.A., Sabic E.M., Saleh A.A., Ebeid T.A. (2020). Effect of dietary supplementation of *Bacillus subtilis* spores on growth performance, oxidative status and digestive enzyme activities in Japanese quail birds. *Trop. Anim. Health Prod.*, 52: 671–680.
- Abd El-Moneim A.E., Shehata A.M., Selim D.A., El-Saadony M.T., Mesalam N.M., Saleh A.A. (2022). *Spirulina platensis* and biosynthesized selenium nanoparticles improve performance, antioxidant status, humoral immunity and dietary and ileal microbial populations of heat-stressed broilers. *J. Thermal Biol.*, 104: 103195.
- Adom K.K., Liu R.H. (2002). Antioxidant activity of grains. *J. Agri. Food Chemist.*, 50: 6182–6187.
- Ahmadi K., Amini B. (2014). Determination of chemical composition and suitable level of wheat middling's in broiler diets. *Int. J. Plant Anim. Environ. Sci.*, 4: 454–459.
- Ahmed M.A., Mohamed M.A., Rashed, L.A., Abd Elbast S.A., Ahmed E.A. (2018). Rice bran oil improves insulin resistance by affecting the expression of antioxidants and lipid-regulatory genes. *Lipids*, 53: 505–515.
- Aito Inoue M., Lackeyram D., Fan M.Z., Sato K., Mine Y. (2007). Transport of a tripeptide, Gly-Pro-Hyp, across the porcine intestinal brush-border membrane. *J. Peptide Sc.: Off. Publ. Europ. Peptide Soc.*, 13: 468–474.
- Alagawany M., El-Saadony M.T., El-Rayes T.K., Madkour M., Loschi A.R., Di Cerbo A., Reda F.M. (2022). Evaluation of dried tomato pomace as a non-conventional feed: Its effect on growth, nutrients digestibility, digestive enzyme, blood chemistry and intestinal microbiota of growing quails. *Food Ener. Secur.*, 11: e373.
- Alam E.A. (2011). Evaluation of antioxidant and antibacterial activities of Egyptian *Maydis stigma* (*Zea mays* hairs) rich in some bioactive constituents. *J. Am. Sci.*, 7: 726–729.
- Al-Harathi M. (2017). The effect of olive cake, with or without enzymes supplementation, on growth performance, carcass characteristics, lymphoid organs and lipid metabolism of broiler chickens. *Braz. J. Poult. Sci.*, 19: 83–90.
- Al-Harathi M.A., Attia Y.A. (2015). Effect of citric acid on the utilization of olive cake diets for laying hens. *Ital. J. Anim. Sci.*, 14: 3966.
- Al-Harathi M., Attia Y. (2016). Effect of citric acid on the nutritive value of olive cake in broiler diets. *Eur. Poult. Sci.*, 76: 1–14.
- Ali A., Devarajan S. (2017). Nutritional and health benefits of rice bran oil. In: Brown Rice, Manickavasagan A., Santhakumar C., Venkatachalapathy N. (eds). Springer: Cham, Switzerland. [https://doi.org/10.1007/978-3-319-59011-0\\_9](https://doi.org/10.1007/978-3-319-59011-0_9).
- Aljubori A., Idrus Z., Soleimani A.F., Abdullah N., Juan Boo L. (2017). Response of broiler chickens to dietary inclusion of fermented canola meal under heat stress condition. *Ital. J. Anim. Sci.*, 16: 546–551.
- Allaby R., Peterson G., Merriwether D., Fu Y.-B. (2005). Evidence of the domestication history of flax (*Linum usitatissimum* L.) from genetic diversity of the *sad2* locus. *Theor. Appl. Gen.*, 112: 58–65.
- Al-Saleh I.A., Billedo G., El-Doush I.I. (2006). Levels of selenium, DL- $\alpha$ -tocopherol, DL- $\gamma$ -tocopherol, all-trans-retinol, thymoquinone and thymol indifferent brands of *Nigella sativa* seeds. *J. Food Comp. Analys.*, 19: 167–175.
- Alshelmani M.I., Loh T.C., Foo H.L., Sazili A.Q., Lau W.H. (2016). Effect of feeding different levels of palm kernel cake fermented by *Paenibacillus polymyxa* ATCC 842 on nutrient digestibility, intestinal morphology, and gut microflora in broiler chickens. *Anim. Feed Sci. Technol.*, 216: 216–224.
- Alshelmani M.A., Abdalla E., Kaka U., Abdul Basit M. (2021). Non-traditional feedstuffs as an alternative in poultry feed. *Advances in Poultry Nutrition Research*. IntechOpen; 2021. Available from: <http://dx.doi.org/10.5772/intechopen.95946>.
- Alyileili S.R., Belal I.E., Hussein A.S., El-Tarabily K.A. (2020). Effect of inclusion of degraded and Non-degraded date pits in broilers' diet on their intestinal microbiota and growth performance. *Animals*, 10: 2041.
- Alzawqari M., Atta M.S., Metwally A., Selim S., Wadaan M.A.M., Kim I.H., Cho S., Eltahan H.M., Alagawany M., Alhotan R.A., Al Sulaiman A.R., Hussein E.O., Saleh A.A. (2023). Growth performance, blood lipids, and fat digestibility of broilers fed diets supplemented with bile acid and xylanase. *Arch. Anim. Breed.*, 66: 451–460.
- Andersson A.A.M., Dimberg L., Aman P., Landberg D. (2014). Recent findings on certain bioactive components in whole grain wheat and rye. *J. Cereal Sci.*, 59: 294–311.
- Anitha B., Moorthy M., Viswanathan K. (2006). Production perfor-

- mance of broilers fed with crude rice bran oil. *Int. J. Poult. Sci.*, 5: 1046–1052.
- Apprich S., Tirpanalan O., Hell J. (2013). Wheat bran-based biorefinery 2: Valorisation of products. *LWT Food Sci. Technol.*, 56: 222–231.
- Arafa S.A., Neven M.M., Nematalla K.M. (2012). Effect of corn silk on characteristics and keeping quality of cake. *J. Biol. Chem. Environ. Sci.*, 7: 371–400.
- Assadi E., Janmohammadi H., Taghizadeh A., Alijani S. (2011). Nutrient composition of different varieties of full-fat canola seed and nitrogen-corrected true metabolizable energy of full-fat canola seed with or without enzyme addition and thermal processing. *J. Appl. Poult. Res.*, 20: 95–101.
- Attia Y.A. (1998). Evaluation of the Egyptian white sorghum grain (Giza-15) as a feedstuff for broiler chick rations. *Egypt. Poult. Sci. J.*, 18: 311–336.
- Attia Y.A., Ashour E.A., Nagadi S.A., Farag M.R., Bovera F., Alagawany M. (2023). Rice bran as an alternative feedstuff in broiler nutrition and impact of Liposorb® and vitamin E-Se on sustainability of performance, carcass traits, blood biochemistry, and antioxidant indices. *Vet. Sci.*, 10: 299.
- Awika J.M., Rooney L.W. (2004). Sorghum phytochemicals and their potential impact on human health. *Phytochemistry*, 65: 1199–1221.
- Ayed H.B., Attia H., Ennouri M. (2015). Effect of oil supplemented diet on growth performance and meat quality of broiler chickens. *Adv. Tech. Biol. Med.*, 4: 156.
- Babatunde O., Park C., Adeola O. (2021). Nutritional potentials of atypical feed ingredients for broiler chickens and pigs. *Animals*, 11: 1196.
- Bai H., Hai C., Xi M., Liang X., Liu R. (2010). Protective effect of maize silks (*Maydis stigma*) ethanol extract on radiation-induced oxidative stress in mice. *Plant Foods Hum. Nutr.*, 65: 271–276.
- Baiao N.C., Lara L.J.C. (2005). Oil and fat in broiler nutrition. *Braz. J. Poult. Sci.*, 1: 129–141.
- Beauregard L., Moustafa A., Sampaio J. (1996). Puntos críticos a considerar en la refinación de aceites para la producción de grasas y margarinas. *Soya Noticias*, 16: 10–15.
- Bera S.K., Kamdar J.H., Kasundra S.V., Patel S.V., Jasani M.D., Maurya A.K., Dash P., Chandrashekar A.B., Rani K., Manivannan N., Janila P., Pandey M.K., Vasanthi R.P., Dobariya K.L., Radhakrishnan T., Varshney R.K., Prasad M. (2019). Steady expression of high oleic acid in peanut bred by marker-assisted backcrossing for fatty acid desaturase mutant alleles and its effect on seed germination along with other seedling traits. *PLoS One*, 14: e0226252.
- Bettaieb I., Bourgou S., Sriti J., Msaada K., Limam F., Marzouk B. (2011). Essential oils and fatty acids composition of Tunisian and Indian cumin (*Cuminum cyminum* L.) seeds: a comparative study. *J. Sci. Food Agri.*, 91: 2100–2107.
- Boeira C.P., Flores D.C.B., Lucas B.N., Santos D., Flores E.M.M., Reis F.L., Morandini L.M.B., Morel A.F., Rosa C.S.D. (2022). Extraction of antioxidant and antimicrobial phytochemicals from corn stigma: a promising alternative to valorization of agricultural residues. *J. Ciência Rural. Ciência Rural Santa Maria*, 52: e20210535.
- Bourgou S., Pichette A., Marzouk B., Legault J. (2012). Antioxidant, anti-inflammatory, anticancer and antibacterial activities of extracts from *Nigella sativa* (black cumin) plant parts. *J. Food Biochem.*, 36: 539–546.
- Bruckert E., Labreuche J., Amarenco P. (2010). Meta-analysis of the effect of nicotinic acid alone or in combination on cardiovascular events and atherosclerosis. *Atherosclerosis*, 210: 353–361.
- Cayan H., Erener G. (2015). Effect of olive leaf (*Olea europaea*) powder on laying hens performance, egg quality and egg yolk cholesterol levels. *Asian-Australas. J. Anim. Sci.*, 28: 538–542.
- Chegeni A., Torki M., Kamyab A. (2011). Effects of  $\beta$ -mannanase-based enzyme in corn-soy and corn-soy canola diets on broiler performance. *J. Appl. Anim. Res.*, 39: 261–268.
- Chiofalo B., Liotta L., Zumbo A., Chiofalo V. (2004). Administration of olive cake for ewe feeding: Effect on milk yield and composition. *Small Rumin. Res.*, 55: 169–176.
- Ciurescu G., Vasilachi A., Idriceanu L., Dumitru M. (2023). Effects of corn replacement by sorghum in broiler chickens diets on performance, blood chemistry, and meat quality. *Italian J. Anim. Sci.*, 22: 537–547.
- Costa E., Miller B., Pesti G., Bakalli R., Ewing H. (2001). Studies on feeding peanut meal as a protein source for broiler chickens. *Poult. Sci.*, 80: 306–313.
- Cromwell G.L., Cline T.R., Crenshaw J.D., Crenshaw T.D., Easter R.A., Ewan R.C., Hamilton C.R., Hill G.M., Lewis A.J., Mahan D.C., Nelssen J.L., Pettigrew J.E., Veum T.L., Yen J.T. (2000). Variability among sources and laboratories in analysis of wheat middlings. *J. Anim. Sci.*, 78: 2652–2658.
- Dal Bosco A., Castellini C., Cardinali R., Mourvaki E., Moscati L., Battistacci L., Servili M., Taticchi A. (2007). Olive cake dietary supplementation in rabbit: immune and oxidative status. *Ital. J. Anim. Sci.*, 6: 761–763.
- Davis J.P., Dean L.L. (2016). Peanut composition, flavor and nutrition. In: *Peanuts*. Elsevier, pp. 289–345.
- Diaw M.T., Dieng A., Mergeai G., Dotreppe O., Youssef I., Hornick J.-L. (2010). Effect of groundnut cake substitution by glandless cottonseed kernels on broilers production: animal performance, nutrient digestibility, carcass characteristics and fatty acid composition of muscle and fat. *Int. J. Poultry Sci.*, 9: 473–481.
- Donaldson J., Dangarembizi R., Mtetwa B., Madziva M., Erlwanger K. (2014). The progressive effects of a high-fat diet on erythrocyte osmotic fragility, growth performance and serum triglyceride and cholesterol levels in guinea fowl (*Numida meleagris*) and Muscovy duck (*Cairina moschata*). *J. Anim. Physiol. Anim. Nutr.*, 98: 867–874.
- Donaldson J., Madziva M.T., Erlwanger K.H. (2017). The effects of high-fat diets composed of different animal and vegetable fat sources on the health status and tissue lipid profiles of male Japanese quail (*Coturnix coturnix japonica*). *Asian-Australas. J. Anim. Sci.*, 30: 700.
- Doré C., Varoquaux F. (2006). Histoire et amélioration de cinquante plantes cultivées. Editions Quae, 840 p.
- Ebeid T., Fayoud A., Abou El-Soud S., Eid Y., El-Habbak M. (2011). The effect of omega-3 enriched meat production on lipid peroxidation, antioxidative status, immune response and tibia bone characteristics in Japanese quail. *Czech J. Anim. Sci.*, 56: 314–324.
- El-Baz A., Khidr R. (2024). Role of feed additives in poultry feeding under marginal environmental conditions. In: *Feed Additives – Recent Trends in Animal Nutrition*, Babinszky L. (ed.). IntechOpen, doi: 10.5772/intechopen.112130
- El-Gendy M.S., El-Gezawy E.S., Saleh A.A., Alhotan R.A., Al-Badwi M.A.A., Hussein E.O.S., El-Tahan H.M., Kim I.H., Cho S., Omar S.M. (2023). Investigating the chemical composition of *Lepidium sativum* seeds and their ability to safeguard against monosodium glutamate-induced hepatic dysfunction. *Foods*, 12: 4129.
- El-Hindawy M., Alagawany M., Mohamed L., Soomro J., Ayasan T. (2021). Influence of dietary protein levels and some cold pressed oil supplementations on productive and reproductive performance and egg quality of laying Japanese quail. *J. Hellenic Vet. Med. Soc.*, 72: 3185–3194.
- El-Sabroun K., Landolfi S., Ciani F. (2024). Feed additives and enrichment materials to reduce chicken stress, maximize productivity, and improve welfare. *Vet. World.*, 17: 2044–2052.
- Fang N., Yu S., Badger T. (2003). Characterization of triterpene alcohol and sterol ferulates in rice bran using LC-MS/MS. *J. Agr. Food Chem.*, 51: 3260–3267.
- FAO (2009). How to feed the world in 2050. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy.
- FAOSTAT (2021). Crops and Livestock Products. Available online: <https://www.fao.org/faostat/en/#data/QCL/visualize> (accessed on 3 July 2023).
- Fernandez M.L., West K.L. (2005). Mechanisms by which dietary fatty acids modulate plasma lipids. *J. Nutr.*, 135: 2075–2078.
- Gagandeep S.D., M'Endiz E., Rao A.R., Kale R.K. (2003). Chemopreventive effects of *Cuminum cyminum* in chemically induced forestomach and uterine cervix tumors in murine model systems. *Nutr. Cancer*, 47: 171–180.
- Galib A.M., Al-Kassi I. (2010). Effect of feeding cumin *Cuminum*

- cyminum* on the performance and some blood traits of broiler chicks. *Pakistan J. Nutr.*, 9: 72–75.
- Garcia A.M., Moumen A., Ruiz D.Y., Alcaide E.M. (2003). Chemical composition and nutrients availability for goats and sheep of two-stage olive cake and olive leaves. *Anim. Feed Sci. Technol.*, 107: 61–74.
- Ghadge V., Upase B., Patil P. (2009). Effect of replacing groundnut cake by soybean meal on performance of broilers. *Vet. World*, 2: 183.
- Gheisari A., Bahadoran R., Tadayonfar S. (2003). Determination of chemical composition and suitable levels of wheat feed screening and macaroni wastes in broiler chick diets. *J. Sci. Technol. Agri. Nat. Res.*, 7: 161–169.
- Ghosh S.K. (2020). *Waste Management as Economic Industry Towards Circular Economy*. Springer.
- Gilani A. H., Jabeen Q., Khan M.A.U. (2004). A review of medicinal uses and pharmacological activities of *Nigella sativa*. *Pakistan J. Bio. Sci.*, 7: 441–451.
- Gopinger E., Xavier E.G., Lemes J.S., Moraes P.O., Elias M.C., Roll V.F. (2014). Carcass yield and meat quality in broilers fed with canola meal. *Br. Poult. Sci.*, 55: 817–823.
- Grigorova S., Abadjieva D., Gjorgovska N. (2017). Influence of natural sources of biologically active substances on livestock and poultry reproduction. *Ira. J. Appl. Anim. Sci.*, 7: 189–195.
- Gualtieri M., Rapaccini S. (1990). Sorghum grain in poultry feeding. *World. Poult. Sci. J.*, 46: 246–253.
- Haldar S., Gan L., Tay S.L., Ponnalagu S., Henry C.J. (2019). Postprandial glycemic and insulinemic effects of the addition of aqueous extracts of dried corn silk, cumin seed powder or tamarind pulp, in two forms, consumed with high glycemic index rice. *Foods*, 8: 437.
- Ham H., Lee Y.Y., Park J.Y., Lee C., Kwak J., Kim I.H., Lee J. (2016). Protective mechanisms of unsaponifiable matter from rice bran against tert-butyl hydroperoxide-induced oxidative damage in HepG2 cells. *J. Food Biochem.*, 40: 526–534.
- Han H., Yan P., Chen L., Luo C., Gao H., Deng Q., Liu L. (2015). Flaxseed oil containing  $\alpha$ -linolenic acid ester of plant sterol improved atherosclerosis in apoE deficient mice. *Oxid. Med. Cell Longev.*, 958217.
- Hao H., Li Z., Leng C., Lu C., Luo H., Liu Y. (2021). Sorghum breeding in the genomic era: opportunities and challenges. *Theor. Appl. Genet.*, 134: 1899–1924.
- Hasanudin K., Hashim P., Mustafa S. (2012). Corn silk (*Stigma maydis*) in healthcare: a phytochemical and pharmacological review. *Molecules* (Basel, Switzerland), 17: 9697–9715.
- Heuzé V., Tran G., Baumont R., Noblet J., Renaudeau D., Lessire M., Lebas F. (2020). Wheat bran. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. <https://www.feedipedia.org/node/726> Last updated on October 14: 11:44.
- Howe P., Meyer B., Record S., Baghurst K. (2006). Dietary intake of long-chain  $\omega$ -3 polyunsaturated fatty acids: Contribution of meat sources. *Nutrition*, 22: 47–53.
- Hu Q., Deng Z. (2011). Protective effects of flavonoids from corn silk on oxidative stress induced by exhaustive exercise in mice. *Afr. J. Biotechnol.*, 10: 3163–3167.
- Hu X., Wang W., Liu L., Wang C., Feng W., Luo Q., Han R., Wang X. (2019). Effects of fat type and emulsifier in feed on growth performance, slaughter traits, and lipid metabolism of Cherry Valley ducks. *Poult. Sci.*, 98: 5759–5766.
- Iji P., Toghyani M., Ahiwe E., Omede A. (2017). Alternative sources of protein for poultry nutrition. *Achieving Sustain. Prod. Poultry Meat*, 2: 237–269.
- Jankowski J., Zdunczyk P., Mikulski D., Juskiewicz J., Naczmannski J., Pomianowski J.F., Zdunczyk P. (2012). Fatty acid profile, oxidative stability, and sensory properties of breast meat from turkeys fed diets with a different n-6/n-3 PUFA ratio. *Eur. J. Lipid Sci. Technol.*, 114: 1025–1035.
- Jansen M., Nuyens F., Buyse J., Leleu S., Van Campenhout L. (2015). Interaction between fat type and lysolecithin supplementation in broiler feeds. *Poult. Sci.*, 94: 2506–2515.
- Javed M.M., Zahoor S., Shafaat S. (2012). Wheat bran as a brown gold: nutritious value and its biotechnological applications. *Afr. J. Microbiol. Res.*, 6: 724–733.
- Jensen M.K., Koh-Banerjee P., Franz M., Sampson L., Gronbaek M., Rimm E.B. (2006). Whole grains, bran, and germ in relation to homocysteine and markers of glycemic control, lipids, and inflammation. *Amer. J. Clin. Nutr.*, 83: 275–283.
- Jimenez-Ramsey L.M., Rogler J.C., Housley T.L., Butler L.G., Elkin R.G. (1994). Absorption and distribution of  $^{14}\text{C}$ -labeled condensed tannin and related sorghum phenolics in chickens. *J. Agri. Food Chemist.*, 42: 963–967.
- Joe B., Lokesh B.R. (1997). Prophylactic and therapeutic effects of n-3 polyunsaturated fatty acids, capsaicin, and curcumin on adjuvant induced arthritis in rats. *J. Nutr. Biochemist.*, 8: 397–407.
- Jóźefiak D., Kierończyk B., Rawski M., Hejdysz M., Rutkowski A., Engberg R.M., Højberg O. (2014). Clostridium perfringens challenge and dietary fat type affect broiler chicken performance and fermentation in the gastrointestinal tract. *Animal*, 8: 912–922.
- Kamei H., Kojima T., Hasegawa M., Koide T., Umeda T., Yukawa T., Terabe K. (1995). Suppression of tumor cell growth by anthocyanins *in vitro*. *Cancer Investigation*, 13: 590–594.
- Kana J.R., Gnonlonfin B.G.J., Harvey J., Wainaina J., Wanjuki I., Skilton R.A., Tegui A. (2013). Assessment of aflatoxin contamination of maize, peanut meal and poultry feed mixtures from different agroecological zones in Cameroon. *Toxins*, 5: 884–894.
- Kang H.K., Kim C.H. (2016). Effects of dietary supplementation with rice bran oil on the growth performance, blood parameters, and immune response of broiler chickens. *J. Anim. Sci. Technol.*, 58: 12.
- Karaivanova M., Drenska D., Ovcharov R. (1990). A modification of the toxic effects of platinum complexes with anthocyanins. *Ekspierimetalna Meditsna i Morfologija*, 29: 19–24.
- Kaup S.R., Arunkumar N., Bernhardt L.K., Vasavi R.G., Shetty S.S., Pai S.R., Arunkumar B. (2011). Antihyperlipidemic activity of *Cynodon dactylon* extract in high-cholesterol diet fed Wistar rats. *Genom. Med. Biomark. Health Sci.*, 3: 98–102.
- Khalifa M., Eltahir E.A.B. (2023). Assessment of global sorghum production, tolerance, and climate risk. *Front. Sustain. Food Syst.*, 7: 1184373.
- Khatun J., Loh T.C., Akit H., Foo H.L., Mohamad R. (2017). Fatty acid composition, fat deposition, lipogenic gene expression and performance of broiler fed diet supplemented with different sources of oil. *Anim. Sci. J.*, 88: 1406–1413.
- Khatun J., Loh T.C., Akit H., Foo H.L., Mohamad R. (2018). Influence of different sources of oil on performance, meat quality, gut morphology, ileal digestibility and serum lipid profile in broilers. *J. Appl. Anim. Res.*, 46: 479–485.
- Kim S.H., Park S.Y., Yu D.J. (2003). Effects of feeding *Aspergillus oryzae* ferments on performance, intestinal microflora, blood serum components and environmental factors in broiler. *Korean J. Poult. Sci.*, 30: 151–159.
- Kim H.-J., Kim J.H., Noh S., Hur H.J., Sung M.J., Hwang J.-T., Park J.H., Yang H.J., Kim M.-S., Kwon D.Y. (2011). Metabolomic analysis of livers and serum from high-fat diet induced obese mice. *J. Proteome Res.*, 10: 722–731.
- Kirrella A.A., Abdo S.E., El-Naggar K., Soliman M.M., Aboelenin S.M., Dawood M.A.O., Saleh A.A. (2021). Use of corn silk meal in broiler diet: effect on growth performance, blood biochemistry, immunological responses, and growth-related gene expression. *Animals*, 11: 1170.
- Kraler M., Schedle K., Domig K.J., Heine D., Michlmayr H., Kneifel W. (2014). Effects of fermented and extruded wheat bran on total tract apparent digestibility of nutrients, minerals and energy in growing pigs. *Anim. Feed Sci. Technol.*, 197: 121–129.
- Kristensen M., Toubro S., Jensen M.G., Ross A.B., Riboldi G., Petronio M., Strup A. (2012). Whole grain compared with refined wheat decreases the percentage of body fat following a 12-week, energy-restricted dietary intervention in postmenopausal women. *J. Nutr.*, 142: 710–716.
- Kristensen M., Knudsen K., Jørgensen H., Oomah D., Bügel S., Toubro S., Tetens I., Astrup A. (2013). Linseed dietary fibers reduce apparent digestibility of energy and fat and weight gain in growing rats. *Nutrients*, 5: 3287–3298.
- Krueger C.G., Vestling M.A., Reed J.D. (2003). Matrix-assisted laser desorption/ionization time-of-flight mass spectrometry of

- heteropolyflavan-3-ols and glucosylated heteropolyflavans in sorghum [*Sorghum bicolor* (L.) Moench]. *J. Agri. Food Chem.*, 15: 538–543.
- Kumar V., Elangovan A.V., Mandal A.B. (2005). Utilization of reconstituted high-tannin sorghum in the diets of broiler chickens. *Asian Australas. J. Anim. Sci.*, 18: 538–544.
- Lai O.M., Jacoby J.J., Leong W.F., Lai W.T. (2019). *Nutritional Studies of Rice-Bran Oil*. AOCS Press: Urbana, IL, USA, pp. 19–54.
- Lamberts L., Delcour J.A. (2008). Carotenoids in raw and parboiled brown and milled rice. *J. Agric. Food Chem.*, 56: 11914–11919.
- Laudadio V., Tufarelli V. (2012). Effect of treated field pea (*Pisum sativum* L. cv *Spirale*) as substitute for soybean meal in a wheat middlings-based diet on egg production and quality of early laying brown hens. *Arch. Geflügelkd.*, 76: 1–5.
- Leeson S., Summers J. (2005). *Commercial Poultry Nutrition*. Department of Animal and Poultry Science, University of Guelph. 3rd ed. University Book.
- Ling W.H., Jones J. (1995). Dietary phytosterols: a review of metabolism, benefits and side effects. *Life Sci.*, 57: 195–206.
- Liu J., Wang C., Wang Z., Zhang C., Lu S., Liu J. (2011). The antioxidant and free-radical scavenging activities of extract and fractions from corn silk (*Zea mays* L.) and related flavone glycosides. *Food Chem.*, 126: 261–269.
- Lu J., Wang K., Tong H., Shi S., Wang Q. (2013). Effects of graded replacement of soybean meal by peanut meal on performance, egg quality, egg fatty acid composition and cholesterol content in laying hens. *Arch. Geflügelkd.*, 77: 43–50.
- Lucchesi M.E., Chemat F., Smadja J. (2004). An original solvent free microwave extraction of essential oils from spices. *Flavour Fragrance J.*, 19: 134–138.
- Madeira M.S., Cardoso C., Lopes P.A., Coelho D., Afonso C., Bandarra N.M. (2017). Microalgae as feed ingredients for livestock production and meat quality: A review. *Livest. Sci.*, 205: 111–121.
- Maki K.C., Davidson M.H., Malik K.C., Albrecht H.H., O'Mullane J., Daggy B.P. (1999). Cholesterol lowering with high-viscosity hydroxypropylmethylcellulose. *Am. J. Cardiol.*, 84: 1198–1203.
- Makled M.N., Afifi O.S. (2001). Sorghum plus methionine supplementation as substituent for yellow corn in broiler diets. *Egypt. Poult. Sci. J.*, 21: 381–397.
- Mansoori B., Modirsanei M., Kiaei S.M.M. (2006). Cumin seed meal with enzyme and polyethylene glycol as an alternative to wheat bran in broiler diets. *J. Sci. Food Agri.*, 86: 2621–2627.
- McCaskill D.R., Zhang F. (1999). Use of rice bran oil in foods. *Food Technol.*, 53: 50–53.
- McDonald P., Edwards R.A., Greenhalgh J.F.D., Morgan C.A., Sinclair L.A., Wilkinson R.G. (2010). *Animal Nutrition*. 7th ed. UK Pearson.
- Meherunnisa L., Imdad H., Abdullah S., Gul H., Farzana M. (2017). Effect of linseed meal on broiler performance and fat content. *Dairy Vet. Sci. J.*, 4: 555628.
- Meng X., Slominski B., Nyachoti C., Campbell L., Genter W. (2005). Degradation of cell wall polysaccharides by combinations of carbohydrase enzymes and their effect on nutrient utilization and broiler chicken performance. *Poult. Sci.*, 84: 37–47.
- Mridula D., Kaur D., Nagra S., Barnwal P., Gurumayum S., Singh K. (2011). Growth performance, carcass traits and meat quality in broilers, fed flaxseed meal. *Asian-Australasian J. Animal Sci.*, 24: 1729–1735.
- Nayebpor M., Hashemi A., Farhomand P. (2007). Influence of soybean oil on growth performance, carcass properties, abdominal fat deposition and humoral immune response in male broiler chickens. *J. Anim. Vet. Adv.*, 6: 1317–1322.
- Nessa F., Ismail Z., Mohamed N. (2012). Antimicrobial activities of extracts and flavonoid glycosides of corn silk (*Zea mays* L.). *Int. J. Biotechnol. Wellness Ind.*, 1: 115–121.
- Ntanios F.Y., Jones P.J.H. (1999). Dietary sitostanol reciprocally influences cholesterol absorption and biosynthesis in hamsters and rabbits. *Atherosclerosis*, 143: 341–351.
- Nyachoti C.M., Atkinson J.L. (1995). The effect of feeding high-tannin sorghum on digestive organ response and overall performance of broiler chicks. *Poult. Sci.*, 74: 125–130.
- Nyamambi B., Ndlovu L.R., Naik Y.S., Kock N.D. (2007). Intestinal growth and function of broiler chicks fed sorghum based diets differing in condensed tannin levels. *South African J. Anim. Sci.*, 37: 202–214.
- Okur N. (2020). The effects of soy oil, poultry fat and tallow with fixed energy: Protein ratio on broiler performance. *Arch. Anim. Breed.*, 63: 91–101.
- Omar S.M., Zahran N.N., Alhotan R.A., Hussein E.O., Galik B., Saleh A.A. (2024). Evaluation of *Salvia hispanica* as a therapeutic agent against sodium arsenic-induced testicular toxicity in a male rats model. *Life*, 14: 109.
- Ouyang K., Xu M., Jiang Y., Wang W. (2016). Effects of alfalfa flavonoids on broiler performance, meat quality, and gene expression. *Canadian J. Anim. Sci.*, 96: 332–342.
- Ozcan C., Cimrin T., Yakar Y., Alasahan S. (2020). Effects of olive cake meal on serum constituents and fatty acid levels in breast muscle of Japanese quail. *S. Afr. J. Anim. Sci.*, 50: 874–880.
- Papadomichelakis G., Pappas A., Tsiplakou E., Symeon G., Sotirakoglou K., Mpekeli V., Fegeros K., Zervas G. (2019). Effects of dietary dried olive pulp inclusion on growth performance and meat quality of broiler chickens. *Livest. Sci.*, 221: 115–122.
- Pappas A.C., Tsiplakou E., Papadomichelakis G., Mitsiopolou C., Sotirakoglou K., Mpekeli V., Haroutounian S., Fegeros K., Zervas G. (2019). Effects of olive pulp addition to broiler diets on performance, selected biochemical parameters and antioxidant enzymes. *J. Hell. Vet. Med. Soc.*, 70: 1687–1696.
- Patra A.K., Samanta G., Pal K. (2011). Effects of an emulsifier on the performances of Khaki Campbell ducks added with different sources of fats. *Front. Agric. China*, 5: 605–611.
- Pekel A., Patterson P., Hulet R., Acar N., Cravener T., Dowler D., Hunter J. (2009). Dietary camelina meal versus flaxseed with and without supplemental copper for broiler chickens: Live performance and processing yield. *Poult. Sci.*, 88: 2392–2398.
- Pesti G., Bakalli R., Qiao M., Sterling K. (2002). A comparison of eight grades of fat as broiler feed ingredients. *Poult. Sci.*, 81: 382–390.
- Ping W., Kwaku G.M., Yiting G., Haile M., Ronghai H., Xuan L., Shilong L., Cheng Z., Liuping Z., Jinhua Z. (2020). Effect of partial replacement of soybean meal with high-temperature fermented soybean meal in antibiotic-growth-promoter-free diets on growth performance, organ weights, serum indexes, intestinal flora and histomorphology of broiler chickens. *Anim. Feed Sci. Technol.*, 269: 114–616.
- Pirmohammadi A., Khalaji S., Yari M. (2019). Effects of linseed expansion on its dietary molecular structures, and on broiler chicks digestive enzymes activity, serum metabolites, and ileal morphology. *J. Appl. Poult. Res.*, 28: 997–1012.
- Platel K., Srinivasan K. (2001). Studies on the influence of dietary spices on food transit time in experimental rats. *Nutr. Res.*, 21: 1493–1503.
- Pour-Reza J., Edriss M.A. (1997). Effects of dietary sorghum of different tannin concentration and tallow supplementation on the performance of broiler chicks. *Br. Poult. Sci.*, 38: 512–517.
- Pradeep U., Geervani K., Eggum B.O. (1993). Common Indian spices: nutrient composition, consumption and contribution to dietary value. *Plant Foods Hum. Nutr.*, 44: 137–148.
- Prajapati N.D., Purohit S.S., Sharma A.K., Kumar T. (2009). *A Handbook on Medicinal Plants. A Complete Source Book*. Agrobios: Jodhpur, India.
- Priolo A., Micol D., Agabriel J. (2001). Effects of grass feeding systems on ruminant meat colour and flavour. A review. *Anim. Res.*, 50: 185–200.
- Punia S., Kumar M., Sandhu K.S. (2021). Rice-bran oil: An emerging source of functional oil. *J. Food Process. Preserv.*, 5: e15318.
- Purushothaman M.R., Vasan P., Mohan B., Ravi R. (2005). Utilization of tallow and rice bran oil in feeding broilers. *Ind. J. Poult. Sci.*, 40: 175–178.
- Qi K., Chen J., Zhao G., Zheng M., Wen J. (2010). Effect of dietary  $\omega 6/\omega 3$  on growth performance, carcass traits, meat quality and fatty acid profiles of Beijing-you chicken. *J. Anim. Physiol. Anim. Nutr.*, 94: 474–485.
- Rahimi S., Azad S.K., Torshizi M.A.K. (2011). Omega-3 enrichment

- of broiler meat by using two oil seeds. *J. Agri. Sci. Technol.*, 13: 353–365.
- Rahman N.A., Wan Rosli W.I. (2014). Nutritional compositions and antioxidative capacity of the silk obtained from immature and mature corn. *J. King Saud Univ. Sci.*, 26: 119–127.
- Rama-Rao S.V., Praharaj N.K., Raju M.V.L.N., Mahapatra S.C., Chawak M.M., Mishra S.K. (1995). Replacement of yellow maize with tannin free sorghum in white leghorn layer diet. *Indian J. Poult. Sci.*, 30: 76–78.
- Ren S.-H., Qiao Q.-Q., Ding X.-L. (2013). Antioxidative activity of five flavones glycosides from corn silk (*Stigma maydis*). *Czech J. Food Sci.*, 2: 148–155.
- Saleh A.A., Hayashi K., Ohtsuka A. (2013). Synergistic effect of feeding *Aspergillus awamori* and *Saccharomyces cerevisiae* on growth performance in broiler chickens; Promotion of protein metabolism and modification of fatty acid profile in the muscle. *J. Poult. Sci.*, 50: 245–250.
- Saleh A.A., Abudabos A.M., Ali M.H., Ebeid T.A. (2019 a). The effects of replacing corn with low-tannin sorghum in broiler's diet on growth performance, nutrient digestibilities, lipid peroxidation and gene expressions related to growth and antioxidative properties. *J. Appl. Anim. Res.*, 47: 532–539.
- Saleh A.A., Kirrella A.A., Dawood M.A.O., Ebeid T.A. (2019 b). Effect of dietary inclusion of cumin seed oil on the performance, egg quality, immune response and ovarian development in laying hens under high ambient temperature. *J. Anim. Physiol. Anim. Nutr.*, 103: 1810–1817.
- Saleh A.A., Paray B.A., Dawood M.A. (2020 a). Olive cake meal and *Bacillus licheniformis* impacted the growth performance, muscle fatty acid content, and health status of broiler chickens. *Animals*, 10: 695.
- Saleh A.A., Zaki A., El-Awady A., Amber K., Badwi N., Eid Y., Ebeid T. A. (2020 b). The effect of substituting wheat bran with cumin seed meal on laying performance, egg quality characteristics and fatty acid profile in laying hens. *Vet. Arhiv.*, 90: 47–56.
- Saleh A.A., Alharthi A.S., Alhotan R.A., Atta M.S., Abd El-Moneim A.E. (2021). Soybean oil replacement by poultry fat in broiler diets: performance, nutrient digestibility, plasma lipid profile and muscle fatty acids content. *Animals*, 11: 2609.
- Sarbaz E., Navidshad B., Aghjeheshlagh F.M. (2018). The effect of peanut pod on performance, small intestine pH and ileum bacteria population in broiler chickens. *South African J. Animal Sci.*, 48: 435–444.
- Sateri S., Seidavi A., Bouyeh M., Kutzler M., Neumann P., Laudadio V., Loperfido F., Tufarelli V. (2017). Effect of olive meal and supplemental enzymes on performance traits, blood biochemistry, humoral immunity response and caecal microbiota of broilers. *S. Afr. J. Anim. Sci.*, 47: 804–812.
- Sayehban P., Seidavi A., Dadashbeiki M., Ghorbani A., Araújo W., Albino L. (2016). Effects of different levels of two types of olive pulp with or without exogenous enzyme supplementation on broiler performance and economic parameters. *Braz. J. Poult. Sci.*, 18: 489–500.
- Sayehban P., Seidavi A., Dadashbeiki M., Ghorbani A., de Araújo W.A.G., Durazzo A., Lucarini M., Gabrielli P., Omri B., Teixeira Albino L.F. (2020). Olive pulp and exogenous enzymes feed supplementation effect on the carcass and offal in broilers: A preliminary study. *Agriculture*, 10: 359.
- Selim S., Hussein E., Abdel-Megeid N.S., Melebari S.J., AL-Harbi M.S., Saleh A.A. (2021). Growth performance, antioxidant activity, immune status, meat quality, liver fat content, and liver histomorphology of broiler chickens fed rice bran oil. *Animals*, 11: 3410.
- Shahryar H.A., Salamadoust R., Lak A., Lotfi A. (2011). Effect of dietary supplemented canola oil and poultry fat on the performance and carcass characterizes of broiler chickens. *Curr. Res. J. Biol. Sci.*, 3: 388–392.
- Singh J., Rasane P., Nanda V., Kaur S. (2023). Bioactive compounds of corn silk and their role in management of glycaemic response. *J. Food Sci. Technol.*, 60: 1695–1710.
- Soumei E.A., Mohebdini H., Toghyani M., Shabani A., Ashayerizadeh A., Jazi V. (2019). Synergistic effects of fermented soybean meal and mannan-oligosaccharide on growth performance, digestive functions, and hepatic gene expression in broiler chickens. *Poult. Sci.*, 98: 6797–6807.
- Srinivasan K. (2005). Spices as influencers of body metabolism: an overview of three decades of research. *Food Res. Int.*, 38: 77–86.
- Statista (2000). Production of Major Vegetable Oils Worldwide from 2012/13 to 2022/2023, by Type. Available online: <https://www.statista.com/statistics/263933/production-of-vegetable-oils-worldwide-since-2000> (accessed on 1 July 2023).
- Sun W., Kang P., Xie M., Hou S.S., Wu T., Mei H.M., Liu Y.L., Hou Y.Q., Wu L.Y. (2016). Effects of full-fat rice bran inclusion in diets on growth performance and meat quality of Sichuan goose. *Br. Poult. Sci.*, 57: 655–662.
- Tanchaonrat P., Ravindran V., Zaefarian F., Ravindran G. (2014). Digestion of fat and fatty acids along the gastrointestinal tract of broiler chickens. *Poult. Sci.*, 93: 371–379.
- Toomer O.T., Livingston M.L., Wall B., Sanders E., Vu T.C., Malheiros R.D., Livingston K.A., Carvalho L.V., Ferket P.R. (2019). Meat quality and sensory attributes of meat produced from broiler chickens fed a high oleic peanut diet. *Poult. Sci.*, 98: 5188–5197.
- Toomer O.T., Livingston M., Wall B., Sanders E., Vu T., Malheiros R.D., Livingston K.A., Carvalho L.V., Ferket P.R., Dean L.L. (2020). Feeding high-oleic peanuts to meat-type broiler chickens enhances the fatty acid profile of the meat produced. *Poult. Sci.*, 99: 2236–2245.
- Torres K.A.A., Pizauro J., Soares C.P., Silva T.G.A., Nogueira W.C.L., Campos L. (2013). Effects of corn replacement by sorghum in broiler diets on performance and intestinal mucosa integrity. *Poult Sci.*, 92: 1564–1571.
- Tufarelli V., Khan R.U., Laudadio V. (2011). Feeding of wheat middlings in lamb total mixed rations: Effects on growth performance and carcass traits. *Anim. Feed Sci. Technol.*, 17: 130–135.
- Tufarelli V., Bozzo G., Perillo A., Laudadio V. (2015). Effects of feeding different lipid sources on hepatic histopathology features and growth traits of broiler chickens. *Acta Histochem.*, 117: 780–783.
- Turcu R.P., Panaite T.D., Untea A.E., Vlaicu P.A., Badea I.A., Mironcusa S. (2021). Effects of grape seed oil supplementation to broilers diets on growth performance, meat fatty acids, health lipid indices and lipid oxidation parameters. *Agriculture*, 11: 404.
- Viveros A., Ortiz L., Rodríguez M., Rebolé A., Alzueta C., Arija I., Centeno C., Brenes A. (2009). Interaction of dietary high-oleic acid sunflower hulls and different fat sources in broiler chickens. *Poult. Sci.*, 88: 141–151.
- Wang H., Lichtenstein A.H., Lamon-Fava S., Jacques P.F. (2006). Association between statin use and serum cholesterol concentrations is modified by whole-grain consumption. *Am. J. Clin. Nutr.*, 100: 1149–1157.
- Yanez R.D., Moumen A., Martin G.A., Molina A.E. (2004). Ruminal fermentation and degradation patterns, protozoa population, and urinary purine derivatives excretion in goats and wethers fed diets based on two-stage olive cake: Effect of PEG supply. *J. Anim. Sci.*, 82: 2023–2032.
- Yao J.H., Han J.C., Wu S.Y., Xu M., Zhong L.L., Liu Y.R., Wang Y.J. (2007). Supplemental wheat bran and microbial phytase could replace inorganic phosphorus in laying hen diets. *Czech J. Anim. Sci.*, 52: 407–413.
- Yu Y., Zhao F., Chen J., Zou Y., Zeng S.L., Liu S.B., Tan H.Z. (2021). Sensitivity of in vitro digestible energy determined with computer-controlled simulated digestion system and its accuracy to predict dietary metabolizable energy for roosters. *Poult. Sci.*, 100: 206–214.
- Zaki A., Jiang S., Zaghloul S., El Rayes T.K., Saleh A.A., Azzam M.M., Ragni M., Alagawany M. (2023). Betaine as an alternative feed additive to choline and its effect on performance, blood parameters, and egg quality in laying hens rations. *Poult. Sci.*, 102: 102710.
- Zampiga M., Meluzzi A., Sirri F. (2016). Effect of dietary supplementation of lysophospholipids on productive performance, nutrient digestibility and carcass quality traits of broiler chickens. *Ital. J. Anim. Sci.*, 15: 521–528.
- Zanini S.F., Colnago G.L., Pessotti B.M.S., Bastos M.R., Casagrande F.P., Lima V.R. (2006). Body fat of broiler chickens fed diets with

- two fat sources and conjugated linoleic acid. *Int. J. Poult. Sci.*, 5: 241–246.
- Zhang R., Ma Q., Tong X., Liu L., Dong L., Huang F., Deng Y., Jia X., Chi J., Zhang M. (2020). Rice bran phenolic extract supplementation ameliorates impaired lipid metabolism in high-fat-diet fed mice through AMPK activation in liver. *J. Funct. Foods*, 73: 104131.
- Zhang Y., Parsons C.M. (1996). Effects of overprocessing on the nutritional quality of peanut meal. *Poult. Sci.*, 75: 514–518.
- Zhao X., Chen J., Du F. (2012). Potential use of peanut by-products in food processing: A review. *J. Food. Sci. Technol.*, 49: 521–529.
- Zimonja O., Stevnebo A., Svihus B. (2007). Nutritional value of diets for broiler chickens as affected by fat source, amylose level and diet processing. *Canadian J. Anim. Sci.*, 87: 553–562.

Received: 6 X 2024  
Accepted: 16 IV 2025