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Cereal by-products as alternative energy sources in poultry diets: A review

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Abstract
The rising global cereal production for human food, feed, and biofuels is accompanied by a surge in quantities of cereal by-products that are not intended for human consumption but are potential alternative energy sources in poultry diets. Their utilization in poultry diets reduces not only poultry feed costs but also the competition between humans and livestock and environmental pollution. Cereal by-products contain a variable amount of nutrients that are useful in poultry nutrition. However, there is limited published information regarding the utilization of cereal by-products as alternative energy sources in poultry diets. Therefore, this review aimed to collate the available information on the proximate composition and inclusion levels of cereal by-products in poultry diets, together with their pertinent issues, for easy retrieval by researchers and nutritionists. In conclusion, good-quality cereal by-products can potentially replace conventional energy sources in poultry diets without adversely affecting poultry performance.

Keywords: Broiler chicken, maize, nutrition, non-conventional, inclusion levels

Introduction

The high demand for energy cereals for food, feed, and biofuel production in developed countries has increased the prices of energy cereal sources in poultry diets, thus hindering the sustainability of poultry production (Qi *et al.*, 2022) [29]. This has prompted interest in the utilization of locally available, cheaper cereal by-products as alternative energy sources in poultry diets. Replacement of conventional energy cereal sources with cereal by-products in poultry diets reduces not only feed costs, which account for about 65-75% of total poultry production costs but also the competition between humans and livestock (Anjum *et al.*, 2014) [5]. Moreover, it reduces environmental pollution, which could otherwise result from improper disposal of cereal by-products as waste in landfills and open dumping sites (Ajila *et al.*, 2012) [2].

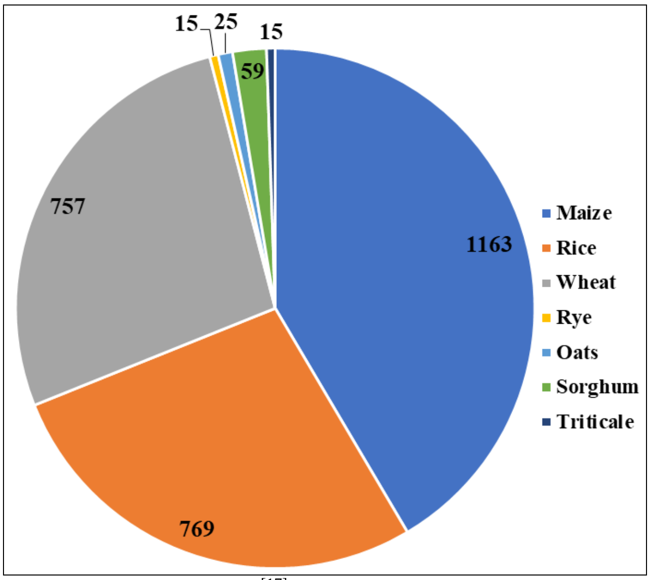
Cereal grains and/or by-products have varying structural, physical, and chemical properties. Cereal grains are made up of three main parts: a seed coat or bran, an endosperm, and a germ. The seed coat is mostly made up of the aleurone layer (a layer beneath the seed coat) and the pericarp, which is high in oil, insoluble dietary fibres, minerals, protein, and vitamins. The endosperm is the most important portion of the cereal grain, containing primarily starch, protein and fibre. It is usually processed into white flour for use as human food. The germ is the reproductive portion of a cereal grain that germinates to become a plant and is high in lipids, sterols, vitamins, minerals, and antioxidants (Ganesan *et al.*, 2020; Brouns *et al.*, 2012) [18, 10]. Cereals are commonly used as energy sources in poultry diets due to their high carbohydrate content. The digestibility of cereals in unprocessed or raw form is hindered by anti-nutritional factors such as phytates, polyphenols, tannins, and trypsin inhibitors (Ganesan *et al.*, 2020) [18].

The high global food demand resulting from the growing human population has stimulated an increase in cereal production (FAOSTAT, 2023) [17]. As a result, there is a surge in the production of cereal by-products during cereal processing for food or beverage, and biofuels (Zhang *et al.*, 2021) [40].

The major cereal grains, accounting for over 90% of global cereal production, are maize, rice, and wheat, while minor cereals include rye, oats, sorghum, and triticale (FAOSTAT, 2023) [17]. Cereal by-products can be utilized in poultry diets to replace conventional energy sources. The cereal by-products have varying proximate composition and metabolizable energy in poultry, as presented in Table 1. The variation can be attributed to several factors, including genetics, environment, fertilizers, method of processing, and storage conditions (Anjum *et al.*, 2014) [5]. Several authors have recommended specific inclusion levels of cereal by-products in diets for particular poultry species and ages (Table 2). This study aimed to collate the available information on the proximate composition and inclusion levels and pertinent issues of major cereal by-products in poultry diets.

Maize by-products

Maize (*Zea mays* L.), also known as corn, is the world's most important crop. In 2020, the global production of maize was approximately 1,163 million metric tonnes (MMT), higher than that of rice (769 MMT) and wheat (757 MMT), as presented in Figure 1. Maize is the main source of metabolizable energy and a standard against which alternative energy sources in poultry diets are compared (Leeson & Summers, 2005) [23]. In starch processing industries, maize by-products, which are high in nutrients, are produced (Zhang *et al.*, 2021) [40]. Maize by-products are the most commonly used feed ingredients in animal feeds. The by-products include maize germ, maize gluten meal, maize distillers dried grains (DDG), and maize distillers dried grains with solubles, etc.



Source: FAOSTAT (2023) [17]

Fig 1: World production quantities of maize, rice, wheat, rye, oats, sorghum and triticale in 2020 (Million Metric Tonnes)

Maize germ meal is obtained during the initial deeming of maize grain during the maize oil extraction process (Qi *et al.*, 2022) [29]. It is highly palatable and high in digestible amino acids and hemicellulose, and it is widely used as a replacement for maize meal in poultry diets. The metabolizable energy of maize germ is similar to that of maize grain (Leeson & Summers, 2005) [23]. Qi *et al.* (2022) [29] found that maize germ meal could be included in the diets of growing ducks up to 12% without adversely affecting their growth performance, serum biochemical indexes, carcass characteristics, meat quality, or standardised ileal digestibility of amino acids. Lopes *et al.* (2019) [24] found that the inclusion of maize germ meal in broiler diets of up to 11.8% optimized body weight gain without affecting feed intake, feed conversion ratio, metabolizable energy, carcass yields, cuts, or offal and meat quality.

Maize gluten meal is produced during the wet milling of maize after the removal of starch, germ, and fibre. Maize gluten meal contains a high crude protein content (60-75%) because most of the protein remains after processing. The residue starch ranges between 15 and 20%, with a low crude fibre of 1%, crude fat of 3%, and ash content of 2%. The limiting factors of maize gluten meal in non-ruminant diets are the low levels of lysine and tryptophan, which warrant their supplementation when maize gluten meal is included in poultry diets (Zhang *et al.*, 2021) [40]. Maize gluten meal is commonly used as an alternative plant protein source in poultry diets. The amino acid digestibility and metabolizable energy of maize gluten meal are higher than those of maize (Leeson & Summers, 2005) [23]. Ávila *et al.* (2020) [7] found that maize gluten meal could be included in up to 10% of rooster diets without adversely affecting the quality of the semen or the body weight of the roosters. In another study, the inclusion of maize gluten meal in diets of up to 7.5% did not negatively affect broiler growth performance (Hosseini *et al.*, 2020) [20].

Maize distillers dried grains (DDG) and maize distillers dried grains with solubles (DDGS) are produced during ethanol or beverage production from maize grain. During the process, the majority of maize starch is fermented, and the unfermented fraction of the grain (i.e., protein, lipids, fibre, and ash) constitutes the distilled grain fraction and the solubles fraction. The distilled grains are dried to produce distillers dried grains (DDG), while the solubles are often added to the distilled grains and dried to produce distillers dried grains with solubles (DDGS). The increasing demand for ethanol in developed countries and the subsequent increase in the production of maize DDGS have increased interest in its utilization in poultry diets. The main challenge in including maize DDGS in poultry diets is the wide variation of nutrient composition, which necessitates proximate analysis of individual maize DDGS sources before diet formulation (Salim *et al.*, 2010) [32]. Once the proximate composition is determined, the true metabolizable energy (TMEn) in kcal/kg can then be predicted by regression analysis based on the proximate components:

[TMEn=2332.736.4 (fat)-76.3 (fibre) + 14.5 (protein)-26.2 (ash)], $R^2 = 0.45$ (Batal & Dale, 2006) [8].

The inclusion level of maize DDGS in poultry diets is recommended to be up to 20% (Wang *et al.*, 2007) [38]. In a broiler study, an inclusion level of up to 16% in diets was found not to adversely affect broiler growth performance and carcass characteristics (Damasceno *et al.*, 2020) [12]. Maize DDGS was included in only up to 12% of the diets of laying hens aged 32-42 weeks without adverse effects on their growth performance or egg production (El-Hack *et al.*, 2019) [1]. In another study in Pekin ducks aged 11-42 d, a 10% inclusion of maize DDGS as a replacement of maize meal and soybean meal in diets did not adversely affect growth performance, carcass characteristics, serum biochemical indexes, meat quality, nutrient utilization, and the standardized ileal digestibility of amino acids in ducks (Ding *et al.*, 2022) [13]. In Japanese quail diets, maize DDGS was included in up to 20% of diets without detrimental effects on growth [9] performance and the quality of eggs while reducing the feed cost (Bittencourt *et al.*, 2019) [9].

Rice by-products

Rice (*Oryza sativa*) is the third most important crop globally after maize and wheat and a staple food for an estimated 3.5 billion people (Seidavi *et al.*, 2021) [33]. During the dehulling and cleaning of brown rice to produce white rice, it is estimated that about 28-35% of the rice grain ends up as by-products (Ganesan *et al.*, 2020) [18]. Rice by-products are abundant in nutrients and phytochemicals, including tocopherols, tocotrienols, polyphenols (ferulic acid and α-lipoic acid), phytosterols, γ-oryzanol, and carotenoids (carotene, lycopene, lutein, and zeaxanthin). These compounds possess antioxidant, anti-inflammatory, and chemo-preventive properties (Ganesan *et al.*, 2020) [18]. The major rice by-products are rice bran and rice polish. Although the two are usually separated during processing, in some cases they may not be separated, and the mixture is referred to as rice bran or rice pollard.

Rice bran generally refers to a mixture of the outermost layers of the rice grain (pericarp, tegmen, and aleurone layers), the embryo, broken endosperm, and varying levels of hulls. Rice bran containing high levels of hulls is highly fibrous and high in ash content, which lowers its nutritional value in poultry (Leeson & Summers, 2005 [23]; Ravindran & Blair, 1991) [30]. Rice bran contains an average to good balance of nutrients, moderate metabolizable energy, and a high content of unsaturated fatty acids. The high levels of unsaturated fats in rice bran make it susceptible to oxidative rancidity; thus, stabilizers such as ethoxyquin are often added to rice-based diets. Raw rice bran contains anti-nutritional factors such as trypsin inhibitors and phytic acid that hinder growth and feed efficiency in poultry (Attia *et al.*, 2023; Leeson & Summers, 2005) [6, 23]. The nutritive value of rice bran is improved through fermentation technologies and the use of feed enzymes (Attia *et al.*, 2023) [6]. Studies in broilers indicate that rice bran can be included in diets up to 10% without negatively affecting growth performance (Attia *et al.*, 2023) [6]. Chen *et al.* (2019) [11] found that defatted rice bran could be included in geese diets up to 20% without adverse effects on growth performance, slaughter performance, and relative weights of the visceral organs. In another study, improved performance, egg composition, and shell quality of layers were observed when fed diets containing 25% rice bran with 250 FTU/kg phytase additive (Habibollahi *et al.*, 2019) [19]. In that study, the deleterious effects of phytates associated with higher rice bran inclusion levels were reversed by the phytase enzyme additive

Table 1: Proximate composition and metabolizable energy (kcal/kg) of common by-products from maize, rice, and wheat (DM basis)

Item	Maize DDG	Maize DDGS	Maize gluten meal	[1]Maize germ	Maize bran	Rice bran	Rice polish	Wheat shorts	Wheat screenings	Wheat bran	Wheat middlings
Dry matter	94	86	90	95.4	90	89.8	90	90	90	90	#
Crude protein	27.8	27	62	12.7	10.8	14.9	11	15	15	16	16
Ether extract	9.2	8.8	2.5	44.3	6.9	17.3	15	4	4.1	4.5	#
Crude fibre	12	6.6	1.3	26.2	8	7.9	2.5	5	3	12	2.7
ash	#	4.4	#	10	2	6.5	9.54	#	#	5.3	#
ME (kcal/kg)	1972	2820	3720	3848	#	1900	2750	2200	3000	1580	2540
Sources	NRC (1994) [27]	Batal *et al.* (2006) [8]	NRC (1994) [27]	Lopes *et al.* (2019) [24]	Hussain *et al.* (2021) [21]	Leeson and Summers (2005) [23]; Attia *et al.*, (2023)	Siddiqui *et al.* (2022) [36]; Leeson and Summers (2005) [23]	Leeson and Summers (2005) [23]	Leeson and Summers (2005) [23]	Zhang *et al.* (2022) [39]; Leeson and Summers (2005) [23]	Saleh *et al.* (2021) [31]

[1]values expressed on a wet basis; #missing value; DDG = distillers dried grains; DDGS = distillers dried grains with solubles; ME = metabolizable energy

Table 2: Recommendations for inclusion levels of some common cereal by-products in poultry diets by different authors

By-product	Species and age	Examined inclusion levels	Major findings	Reference
Maize germ	Ducks (10-42 d)	0, 3, 6, 9, or 12%	Inclusion of up to12% maintained growth rate, carcass characteristics, serum biochemical parameters, meat quality, and dietary SIDAA	Qi *et al.* (2022) [29]
	Broilers (8-21, 22-35 d)	4, 8, 12, 16, and 20%	Inclusion of up to 11.8% optimized growth performance	Lopes *et al.* (2019) [24]
Maize gluten meal	Roosters (68-72 weeks)	0, and 10%	Inclusion of up to 10% maintained semen quality and body weight	Ávila *et al.* (2020) [7]
	Broilers (15-42 d)	0, 2.5, 5 and 7.5%	Inclusion of up to 7.5% had no adverse effects on growth performance	Hosseini *et al.* (2020) [20]
Maize DDGS	Broilers (22-42 d)	0, 1, 4, 7, 10, 13, and 16%	Inclusion of up to 16% inclusion level maintained growth performance, carcass, and cut yield	Damasceno *et al.* (2020) [12]
	Laying hens (32-42 weeks)	0, 6, 12, and 18% with or without exogenous enzyme mixture	Inclusion of up to 12% optimized performance and egg characteristics	El-Hack *et al.* (2019)[1]
	Pekin ducks (11-42 d)	0, 5, 10, 15, and 20%	Inclusion of up to 10% had no effect on growth performance, carcass characteristics, and meat quality	Ding *et al.* (2022) [13]

DDGS = distillers dried grains with solubles; SIDAA = standardized ileal digestibility of amino acids

Table 2: Continued

By-product	Species and age	Examined inclusion levels	Major findings	Reference
Rice bran	Broiler (1-5 weeks)	0, 5, 10% with or without feed additives (Liposorb® and vitamin E-Se)	Inclusion of up to 10% did not adversely affect growth performance	Attia *et al.* (2023) [6]
	Laying hens (48-62 weeks)	0, 15, and 25% with or without phytase supplementation	Inclusion of rice bran up to 25% with phytase in diets improved performance, egg composition, and shell quality	Habibollahi *et al.* (2019) [19]
	Geese (29-70 d)	0, 10, 20, 30, or 40%	Inclusion of up to 20% did not negatively affect growth performance, slaughter performance, and relative weights of the viscera	Chen *et al.* (2019) [11]
Rice polish	Broiler (7-28, 29-42 d)	0, 15, or 20% with or without feed additives	Inclusion of up to 15 or 20% maintained growth and feed efficiency	El-Ghamry *et al.* (2005) [16]
Rice bran oil	Broilers (1-38 d)	0, 50, 100% replacement of palm oil (4-5% in diet)	Replacement of up to 50% did not adversely affect broiler growth performance, or carcass characteristics, while it enhanced the fatty acid deposition of the broiler breast meat	Al-Abdullatif *et al.* (2023)[4]
Wheat bran	Broilers (1-21 d, 22-42 d)	0 and 3%	Inclusion of up to 3% enhanced nutrient digestibility	Shang *et al.* (2020) [35]
Wheat middling's	Broilers (11-30 d, 31-49 d)	0 and 5%	Inclusion of up to 5% improved growth performance and nutrient digestibility	Saleh *et al.* (2021) [31]

Phytate comprises 28.2% phosphorus (phytate phosphorus), which cannot be efficiently utilized by non-ruminant animals (McCuistion *et al.*, 2019) [25]. Additionally, phytate lowers the digestibility of calcium (Ca), magnesium (Mg), trace minerals (zinc and iron), and protein and lowers energy utilization in chickens (Moss *et al.*, 2018) [26]. The inclusion of phytate-degrading enzymes in poultry diets to liberate bound phosphorus is widely practised. This is highly beneficial in rice bran-based diets because of the high levels of phytate contained (Habibollahi *et al.*, 2019) [19].

Rice polish is very common in rice-growing areas, especially during rice milling seasons. It constitutes about 10% of the paddy by weight. Rice polish is produced from the inner layers of the rice kernel during rice milling (Ravindran & Blair, 1991) [30]. Rice polish is lower in crude fibre and higher in fat content compared to rice bran (Leeson & Summers, 2005) [23]. Due to the high variation in nutrient composition and adulteration of rice polish, it is recommended to analyse the proximate composition of each rice polish consignment for use in diet formulation. Rice polish has been reported not to adversely affect broiler growth performance when included up to 15% in diets, depending on its quality (El-Ghamry *et al.*, 2005) [16].

Rice bran oil is extracted from the germ and inner husk of the rice grain during processing. It contains a significant amount of oil, ranging between 10% and 23%, depending on the genotype and degree of milling (Dunford, 2019) [14]. Rice bran oil contains high levels of health-beneficial bioactive compounds such as oryzanol, tocopherols, and tocotrienols, which increase its nutritive value (Selim *et al.*, 2021) [34]. These bioactive compounds possess antioxidant and anti-inflammatory properties as well as lower cholesterol levels and boost the immune response (Punia *et al.*, 2021) [28]. Rice bran oil fatty acid composition comprises 41% monounsaturated fatty acids (MUFA), 36% polyunsaturated fatty acids (PUFA), and 19% saturated fatty acids (SFA) (Kahlon, 2009) [21]. Compared to palm oil, rice bran oil contains higher metabolizable energy and its ether extract and fatty acids are highly digestible in broilers than those of palm oil (Song *et al.*, 2022) [37]. Rice bran oil is included in poultry diets to boost dietary energy density. In a recent study evaluating the effect of replacing palm oil with rice bran oil in broilers (1-38 d), there were no adverse effects on broiler growth performance or carcass characteristics, while it enhanced the fatty acid deposition of the broiler breast meat (Al-Abdullatif *et al.*, 2023) [4].

Wheat by-products

Wheat (*Triticum aestivum)* is the third most-produced cereal crop globally after maize and rice (FAOSTAT, 2023) [17]. During the cleaning of wheat and production of wheat flour for food production, approximately 40% of the wheat grain is released in the form of various wheat by-products (Leeson & Summers, 2005) [23]. The wheat by-products are called by different names in different countries. The main wheat by-products are wheat bran, wheat middlings and wheat screenings.

Wheat bran represents the outer husk, which is usually very fibrous and high in protein but low in metabolizable energy (Leeson & Summers, 2005) [23]. The fibre comprises mostly arabinoxylans and some cellulose and β-glucans, which makes wheat bran less digestible in poultry. However, arabinoxylan or arabino-xylo-oligosaccharides derived from wheat bran have been reported to be beneficial to gut health, such as gut microbiota, which in turn improves the digestive process in poultry (Akhtar *et al.*, 2012 [3]; Eeckhaut *et al.*, 2008) [15]. Thus, moderate inclusion of wheat bran in poultry diets may improve feed efficiency. In a broiler study, it was reported that the inclusion of wheat bran up to 3% in the diet enhanced nutrient digestibility without any side effects on growth performance (Shang *et al.*, 2020) [35]. High inclusion of wheat bran in poultry diets reduces feed intake and growth rate and may cause excessive wetting of poultry manure (Leeson & Summers, 2005) [23].

Wheat middlings are the main by-product obtained as flour during the grinding of wheat through a series of grinders of decreasing size (Leeson & Summers, 2005) [23]. Wheat middlings contain high levels of non-starch polysaccharides such as cellulose, arabinoxylans, hemicelluloses, and lignin, the same as in wheat bran (Saleh *et al.*, 2021) [31]. Thus, inclusion levels of wheat middlings in poultry diets should be considered with caution as they are less digestible. According to Saleh *et al.* (2021) [31], the inclusion of wheat middlings up to 5% in broiler diets positively affected growth performance, nutrient digestibility, lipid peroxidation, and the fatty acid profile in muscles.

Wheat screenings (broken and cracked wheat grains) are obtained during the cleaning and grading of wheat meant for humans. Screenings may also contain other materials, such as wild oats, buckwheat, and weed seeds. The nutrient profile of screenings is close to that of wheat, and the number 1 and 2-grade screenings may be included up to 40% in broiler and layer diets (Leeson & Summers, 2005) [23].

Conclusion

The use of locally available cereal by-products to replace conventional feed ingredients in poultry feeds is beneficial in reducing feed costs, the competition between humans and livestock, and environmental pollution. The inclusion levels of cereal by-products in poultry diets are limited by their poor nutrient profile and content of anti-nutritional factors. Further research is needed to determine the effect of processing methods, fermentation technologies and feed additives on the nutritional value of the cereal by-products.

References

1. Abd El-Hack ME, Mahrose KM, Attia FA, Swelum AA, Taha AE, Shewita RS, *et al.* Laying performance, physical, and internal egg quality criteria of hens fed distillers dried grains with solubles and exogenous enzyme mixture. Animals. 2019;9(4):150. https://doi.org/10.3390/ani9040150
2. Ajila CM, Brar SK, Verma M, Prasada Rao UJS. Sustainable solutions for agro processing waste management: An overview. Environmental Protection Strategies for Sustainable Development; c2012. p. 65-109.
3. Akhtar M, Tariq AF, Awais MM, Iqbal Z, Muhammad F, Shahid M, *et al.* Studies on wheat bran Arabinoxylan for its immunostimulatory and protective effects against avian coccidiosis. Carbohydrate Polymers. 2012;90(1): 333-339. https://doi.org/10.1016/j.carbpol.2012.05.048
4. Al-Abdullatif A, Hussein E, Suliman G, Akasha M, Al-Badwi M, Ali H, *et al.* Evaluating rice bran oil as a dietary energy source on production performance, nutritional properties and fatty acid deposition of breast meat in broiler chickens. Foods. 2023;12(2):366.
5. Anjum MA, Hussain Z, Khan SH, Ahmad N, Amer MY, Iftikhar N, *et al.* Assessment of poultry feed ingredients used in commercial compound feed. Pakistan Journal of Life and Social Sciences. 2014;12(2):69-73.
6. Attia YA, Ashour EA, Nagadi SA, Farag MR, Bovera F, Alagawany M, *et al.* 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. Veterinary Sciences. 2023;10(4):299. https://doi.org/10.3390/vetsci10040299
7. Ávila SLCD, Oliveira COD, Rodrigues TA, Tavares AT, Soares SL. Replacement of corn and soybean meal with corn gluten meal on rooste's diet. Turkish Journal of Veterinary & Animal Sciences. 2020;44(4):798-804.
8. Batal AB, Dale NM. True metabolizable energy and amino acid digestibility of distillers dried grains with solubles. Journal of Applied Poultry Research. 2006;15(1):89-93. https://doi.org/10.1093/japr/15.1.89
9. Bittencourt TM, Lima HJDA, Valentim JK, Martins ACDS, Moraleco DD, Vaccaro BC, *et al.* Distillers dried grains with solubles from corn in diet of Japanese quails. Acta Scientiarum. Animal Sciences; c2019. p. 41. https://doi.org/10.4025/actascianimsci.v41i1.42749
10. Brouns F, Hemery Y, Price R, Anson NM. Wheat aleurone: separation, composition, health aspects and potential food use. Critical Reviews in Food Science and Nutrition. 2012;52(6):553-568.
11. Chen X, Yang H, Wang Z. The effect of different dietary levels of defatted rice bran on growth performance, slaughter performance, serum biochemical parameters, and relative weights of the viscera in geese. Animals. 2019;9(12):1040. https://doi.org/10.3390/ani9121040
12. Damasceno JL, Rocha CS, Eyng C, Broch J, Savaris VD, Wachholz L, *et al.* Corn distillers' dried grains with solubles to feed broiler chickens from 22 to 42 D of age. Journal of Applied Poultry Research. 2020;29(3):573-583. https://doi.org/10.1016/j.japr.2020.03.004
13. Ding XM, Qi YY, Zhang KY, Tian G, Bai SP, Wang JP, *et al.* Corn distiller's dried grains with solubles as an alternative ingredient to corn and soybean meal in Pekin duck diets based on its predicted AME and the evaluated standardized illegal digestibility of amino acids. Poultry Science. 2022;101(8):101974. https://doi.org/10.1016/j.psj.2022.101974
14. Dunford NT. Chemistry of rice bran oil. In Rice bran and rice bran oil. AOCS Press; c2019. p. 1-18.
15. Eeckhaut V, Van Immerseel F, Dewulf J, Pasmans F, Haesebrouck F, Ducatelle R, *et al.* Arabinoxylooligosaccharides from wheat bran inhibit Salmonella colonization in broiler chickens. Poultry Science. 2008;87(11):2329-2334. https://doi.org/10.3382/ps.2008-00193
16. El-Ghamry AA, Al-Harthi MA, Attia YA. Possibility to improve rice polishing utilisation in broiler diets by enzymes or dietary formulation based on digestible amino acids. Arch Geflugelk. 2005;69:49-56.
17. FAOSTAT. FAOSTAT Database, Food and Agriculture Organization of the United Nations. Rome, Italy; c2023. https://www.fao.org/faostat/en/#compare. 2023 Sep 12.
18. Ganesan AR, Rajauria G. Cereal-Based Animal Feed Products. Innovative Processing Technologies for Healthy Grains; c2020. p. 199-226.
19. Habibollahi M, Abousadi MA, Nakhaee P. The effect of phytase on production performance, egg quality, calcium and phosphorus excretion, and fatty acids and cholesterol concentration in hy-line layers fed diets containing rice bran. Journal of Applied Poultry Research. 2019;28(3):688-698. https://doi.org/10.3382/japr/pfz020
20. Hosseini SA, Alizadeh-Ghamsari AH, Lotfollahian H, Tavakkoli M, Barfourooshi HJ. Effects of different levels of corn gluten feed on performance, immune responses, intestinal morphology and some blood parameters of broiler chickens. Animal Production. 2020;22(1):93-103.
21. Hussain M, Qamar A, Saeed F, Rasheed R, Niaz B, Afzaal M, *et al.* Biochemical properties of maize bran with special reference to different phenolic acids. Inter. J. of Food Properties. 2021;24(1):1468-1478. https://doi.org/10.1080/10942912.2021.1973026
22. Kahlon TS. Rice bran: Production, composition, functionality and food applications, physiological benefits. CRC Press, Taylor & Francis Group: Boca Raton, FL, USA; c2009. p. 305-322.
23. Leeson S, Summers JD. Commercial poultry nutrition third edition. Nottingham University Press, UK. 32005, 98.
24. Lopes EC, Rabello CBV, Santos MJBD, Lopes CDC, Oliveira CRCD, Silva DAD, *et al.* Performance and carcass characteristics of broilers fed whole corn germ. Revista Brasileira de Zootecnia; c2019. p. 48.

25. McCuistion KC, Selle PH, Liu SY, Goodband RD. Sorghum as a feed grain for animal production. Sorghum and Millets; c2019. p. 355-391. https://doi.org/10.1016/B978-0-12-811527-5.00012-5
26. Moss AF, Liu SY, Selle PH. Progress in comprehending the phytate–phytase axis in chicken-meat production. Animal Production Science. 2018;58(10):1767-1778. https://doi.org/10.1071/AN17594
27. NRC. Nutrient requirements of poultry: National Research Council. National Academies Press; c1994.
28. Punia S, Kumar M, Sandhu KS, Whiteside WS. Rice-bran oil: An emerging source of functional oil. Journal of Food Processing and Preservation. 2021;45(4):e15318. https://doi.org/10.1111/jfpp.15318
29. Qi YY, Zhang KY, Tian G, Bai SP, Ding XM, Wang JP, *et al.* Effects of dietary corn germ meal levels on growth performance, serum biochemical parameters, meat quality, and standardized illegal digestibility of amino acids in Pekin ducks. Poultry Science. 2022;101(5): 101779. https://doi.org/10.1016/j.psj.2022.101779
30. Ravindran V, Blair R. Feed resources for poultry production in Asia and the Pacific region. I. Energy sources. World's Poultry Science Journal. 1991;47(3): 213-231. https://doi.org/10.1079/WPS19910018
31. Saleh AA, Elnagar AM, Eid YZ, Ebeid TA, Amber KA. Effect of feeding wheat middlings and calcium lignosulfonate as pellet binders on pellet quality growth performance and lipid peroxidation in broiler chickens. Veterinary Medicine and Science. 2021;7(1):194-203.
32. Salim HM, Kruk ZA, Lee BD. Nutritive value of corn distillers dried grains with solubles as an ingredient of poultry diets: A review. World's Poultry Science Journal. 2010;66(3):411-432. https://doi.org/10.1017/S0043933910000504
33. Seidavi A, Azizi M, Swelum AA, Abd El-Hack ME, Naiel MA. Practical application of some common agro-processing wastes in poultry diets. World's Poultry Science Journal. 2021;77(4):913-927. https://doi.org/10.1080/00439339.2021.1960461
34. Selim S, Hussein E, Abdel-Megeid NS, Melebary SJ, Al-Harbi MS, Saleh A, *et al.* Growth performance, antioxidant activity, immune status, meat quality, liver fat content, and liver histomorphological of broiler chickens fed rice bran oil. Animals. 2021;11(12):3410. https://doi.org/10.3390/ani11123410
35. Shang Q, Wu D, Liu H, Mahfuz S, Piao X. The impact of wheat bran on the morphology and physiology of the gastrointestinal tract in broiler chickens. Animals. 2020;10(10):1831. https://doi.org/10.3390/ani10101831
36. Siddiqui R, Mondal BC, Kumar R, Kaur M, Kumar A, Palod J, *et al.* Effect of replacing rice polish with mulberry (*Morus alba*) leaf powder in diet containing phytase enzyme on performance and haemato-biochemical parameters of commercial laying hens. Indian Journal of Veterinary Sciences & Biotechnology. 2022;18(1):17-22.
37. Song M, Zhao F, Ye X, Xie J, Sa R, Zhang G, *et al.* A comparative evaluation on the energetic values and digestibility of fatty acids in rice bran oil and palm oil for broilers. Poultry Science. 2022;101(8):101954. https://doi.org/10.1016/j.psj.2022.101954
38. Wang Z, Cerrate S, Coto C, Yan F, Waldroup PW. Utilization of distillers dried grains with solubles (DDGS) in broiler diets using a standardized nutrient matrix. Inter. J. of Poultry Science. 2007;6(7):470-477.
39. Zhang AR, Wei M, Yan L, Zhou GL, Li Y, Wang HM, *et al.* Effects of feeding solid-state fermented wheat bran on growth performance and nutrient digestibility in broiler chickens. Poultry Science. 2022;101(1):101402. https://doi.org/10.1016/j.psj.2021.101402
40. Zhang R, Ma S, Li L, Zhang M, Tian S, Wang D, *et al.* Comprehensive utilization of corn starch processing by-products: A review. Grain & Oil Science and Technology. 2021;4(3):89-107. https://doi.org/10.1016/j.gaost.2021.08.003