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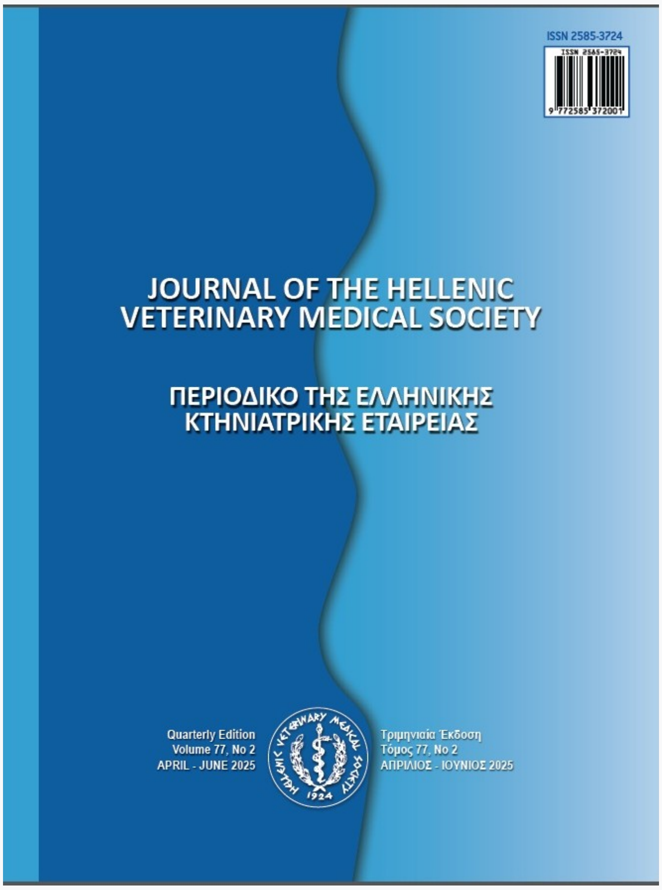

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Review article
Ανασκόπηση

Wheat Bran Beyond a Fiber Source for Sustainable Poultry Nutrition: A Comprehensive Review

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ABSTRACT: Wheat bran (WB), but also hulls from rice, oat, sunflower and soybean, wood chips, and industrial fiber byproducts are among the main sources of insoluble fiber for sustainable poultry production. Insoluble fiber (IF) in poultry is more than a diet-diluent because of it improves performance, digestive tract ecology, and health in poultry. Feeding of 2.5-3.5% of IF could improve feed efficiency and nutrient digestibility, whereas soluble dietary fiber (SDF) causes increased viscosity, intestinal transit time, and decreased feed intake, digestibility, and growth rate. The nutritional advantages of WB include high fiber (48-53%), protein (9.6-18.6%), vitamin B, betaine, and minerals, as well as the improvement of health status and production. Microbial fermentation is utilized to enhance the nutritional properties of wheat bran fiber by incorporating fungi, bacteria, and yeast. Wheat bran, rich in dietary fiber microorganisms like *Aspergillus, Saccharomyces, Lactobacillus,* and *Bacillus*. Used in fermentation process under controlled conditions (temperature, pH, oxygen, and moisture levels) promote microbial growth, improves nutrient content, digestibility, and gastrointestinal health, making wheat bran a valuable feed ingredient for poultry nutrition. The main challenge of WB feeding is due to its high fiber content, anti-nutritional factors affecting the digestion and absorption of nutrients, intestinal viscosity, and microbiota. Diets diluted with WB affect the amount of endogenous and exogenous enzymes, intestinal length and relative weight of the gizzard. Intrinsic phytase is one of the less discussed advantages of WB in monogastric nutrition; it increases the bioavailability of phosphorus and several other nutrients and reduces the need to add exogenous phytase and phosphate sources. Endogenous WB phytase was completely released at pH 3-5 by microbial phytase from the aleurone layer. Phytase activity depends on the type of wheat and phytase matrix. The addition of appropriate levels of exogenous enzymes is effective in regulating the gene expression of digestive enzymes and improves the release of trace elements and bone matrix. In this review, based on the available literature, we concluded that the benefits of using WB were much greater than other fiber sources, but more research is needed to compare this valuable fiber source in terms of gut ecology, gene expression, digestibility, behavior, and its interactions with different fat sources.

Keyword: enzymes; fermented feed; fiber; gut health; phytate; poultry sustainability; wheat bran.

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INTRODUCTION

The amount of wheat grain production in the world and Iran is 760 and 14.4 million tons per year (FAO, 2022) and 72% of the total wheat production is converted into flour. Considering that 15-21% of the wheat grain weight is wheat bran, it can be predicted that wheat flour and wheat bran produced worldwide will be 555 and 120, respectively, and in Iran, 10.5 and 2.1 million tons. Approximately 450,000 to of wheat bran is consumed by the poultry industry in Iran, and it is necessary to have more comprehensive information about it. More than 95% of wheat bran is produced as livestock and poultry feed (Javed et al., 2012). Iran's poultry and livestock industries require 9 and 12 million tons of feed for sustainable animal production, respectively.

The physical and visual characteristics of wheat are important. The average wheat grain length, width and thickness was 7.36, 3.27, 2.98 (length of the Sardari and Ghod Variety 6.64 and 7.08) mm (Tabatabaeefar, 2003). The length for winter and spring wheat was 7.58 and 6.30 mm (Zapotoczny, 2011). Wheat grip (for 1000-kernel) weight in normal (33.5-34.3 g) and durum wheat (43.5-44.9g) (Abdul-Razzaq et al., 2018; Adel Karim and Mahmoud, 2021; Safi et al., 2022), and grain volume (29-42 mm^3 and average: 35 mm^3) (Al-Mahasneh and Rababh, 2007; Karimi et al.,2009). The size, quality and composition of the WB produced are affected by the variety and type (spring and winter) of the wheat and flour production machines (Figure 1).

Various sieves have been made to determine the size of WB; however, in the poultry industry, there is no separation between the sizes. The WB size in normal wheat is 170-900 µm (170 or flour, 280, 425 medium, and for bread, 750, 900 or very coarse for bread) and durum wheat 115-1500 µm. The large particles of WB (1.6-1.8 mm) are generally darker than the small particles (1 mm) (Radenkovs and Klava, 2012).

The main purpose of using agricultural and animal by-products (processed hatchery litter and others) in livestock and poultry nutrition is to make the rations economical (cheap), dilute, preserve the environment, and use the benefits of insoluble fiber (Mashayekhi and Salahi, 2015).

Researchers are exploring alternative sources for poultry feed ingredients due to the scarcity and rising costs of traditional options. Agricultural wastes and by-products like wheat bran, rice husk, sour cherry kernel, palm kernel, cassava pulp, rapeseed meal, and corn meal are being considered. However, these materials cannot be directly used due to their high crude fiber content. Fermentation is an emerging process that involves converting complex substrates into simpler molecules using bacteria, fungi, and other microorganisms. This process enhances the

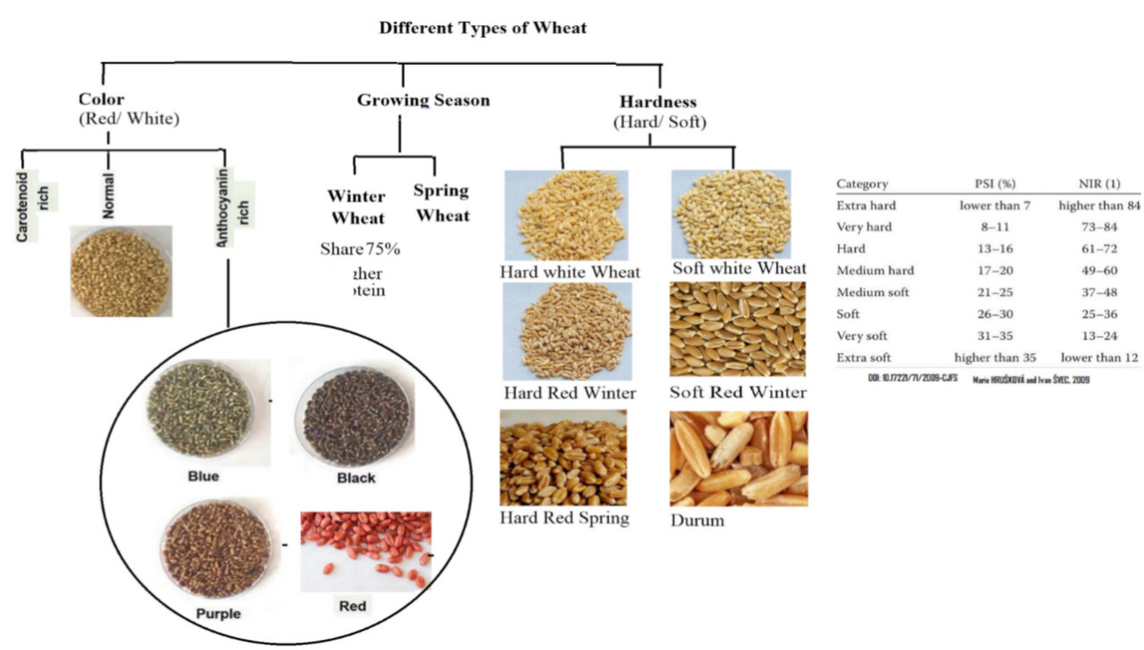

Figure 1. Different type of wheat grain (color, growing season and hardness).

nutrient content of feed ingredients and can also be applied to agricultural waste materials to improve their nutritional value for broiler feed. Additionally, fermentation offers a cost-effective feed source for the poultry industry and transforms waste materials into usable products. Various bacterial and fungal strains are utilized in this fermentation process (Ahmad et al.,2023). Wheat bran is the main by-product of the wheat milling industry, and it is a coarse layer of wheat kernel that is separated from the kernel and contains high fiber and protein content, high volume, and low metabolic energy (Kuzmicky et al., 1977). The WB is edible and rich in fiber (48-53%) (Posner,2009), and it is very suitable for microbial digestion; in addition, slow fermentation in the rumen slows the rate of pH drop (Precision Fermentation Co, 2021).

It is necessary to examine the benefits of using this valuable source of fiber and to take a new look at the use of WB in poultry and livestock nutrition. The addition of WB to broiler and parent stock feeds is a dilute nutrient that has many goals, such as diluting the poultry diet, increasing the uniformity of the flock, using the prebiotics property of WB to modulate gut microbial ecosystem (D'hoe et al., 2018), stimulating gizzard development (inclusion of insoluble fibers 2 to 3%), making diet cheaper, and preventing abnormal behavior of poultry. We know that abnormal behavior found in birds when the poultry ration does not provide a minimum amount of fiber (Mateos et al., 2012). However, its other effects should not be neglected, including reduced nutrient digestibility and performance. Moreover, after banning the use of growth-promoting antibiotics in poultry diet in 2006, one of the strategies in the poultry sector is to increase the level of fiber consumption to reduce nutritional and digestive disorder and improve poultry sustainability.

COMPOSITION OF WHEAT BRAN

Wheat bran consists of different histological layers, including the outer pericarp (epidermis and hypodermis), inner pericarp (tube cells and cross cells), testa (seed coat), hyaline layer, aleurone layer (single outer layer surrounding the endosperm, remains attached to bran during milling), starchy endosperm, germ (scutellum and embryonic axis), and brush (Figure 2; Surget and Barron, 2005). In addition, starchy endosperm (80-85% of the grain, composed of starch and proteins), the outer layer (12-17% of the grain, mainly consists of fiber, vitamins, minerals, and antioxidants), and wheat germ (3%) (Hemery et al., 2010) (Figure 3; Heinze, 2017).

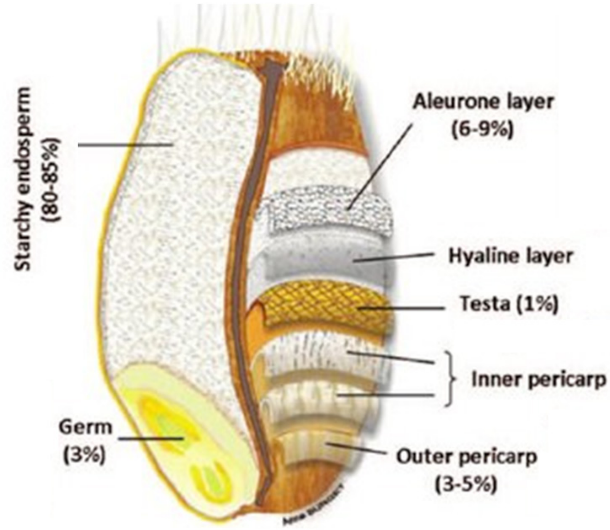

Figure 2. Histological composition of wheat grain (from Surget and Barron, 2005).

Usually, xylanase enzymes are used for wheat-based diets, acting on arabinoxylan (high water holding capacity and increased intestinal viscosity) and releasing the nutrients trapped inside the cell wall, making them available to the enzymes of the digestive system (Bedford, 1997). The amount of separate bran and its composition depends on the wheat strain (variety and layer thickness, shape of

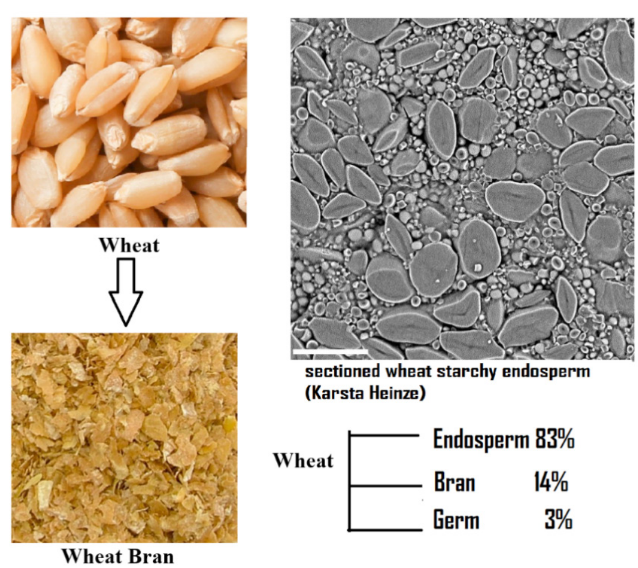

Figure 3. Wheat grain, bran, sectioned wheat starchy endosperm showing the dense packing of starch granules (30 μm) (from Heinze, 2017).

grain), and quality of machinery or milling method (Wang et al., 2022). Therefore, the levels of nutrients and metabolizable energy in the available research reports are very different (Slominski et al., 2004; Wan et al., 2009).

The composition of WB is listed in Tables 1 and 2. The WB is a source of fiber: in whole wheat grain, WB,and wheat germ are 132, 446, and 177 g/kg, respectively (Stevenson et al., 2012). The composition of WB based on different research summarized by Onipe et al. (2015) was as follows: dietary fiber (33-63%), moisture (8-12.7%), ash (4-8), protein (9.6-18.6%), total carbohydrates (60-75%), starch (9-39% DM). The average crude fat, ash, crude protein, crude fiber content of samples was determined to be 4.80, 5.68, 16.23, 8.60 (as % of DM) respectively (Lotfi et al., 2019). In addition, the amounts of ash, crude protein, crude fat, NDF, and EDF in wheat bran are 5.1, 15.4, 3.6, 41, and 10.7%, respectively (Chee et al., 2005). Ranum (2000) reported a high amount of cellulose and low amount of gluten in WB. Another study showed that WB ingredients include cellulose (32.1%), hemicellulose (NDF – ADF) (29.2%), lignin (16.4%), and extracts (22.3%) (Xiao et al. 2019).

The amount of NDF reported by different researchers is 34.7-47.4% in Iran (Ghorbani and Nikkhah, 2005), 30-45.8 in California, USA (Arosemena et al., 1994).

The seasonal effect on wheat bran composition showed that DM, NDF, ADF and CP (%) in the samples were higher in summer than in winter (Eslamian et al., 2017). The results of Bashtani etal. (2014) stated that the size of the particles affects the amount of NDF, and the highest amount of NDF is related to the size of particles larger than 1.18 mm (coarse), which is due to the high amount of bran shells in large samples. The difference in CP of WB among the nine varieties was approximately 30% (Farrel et al., 1967). When the particle size is smaller than 0.25 mm, the amount of crude protein is higher (Bashtani et al., 2014).

Soluble dietary fiber (glucan and xylans) comprises 5% of total dietary fiber (DF) (Andersson et al., 2014), and WB water-insoluble fiber (95%) is made of arabinoxylan (19-25%), starch (17-29%), protein (14-18%), lignin (~3%), β-glucans (1-3%), phytic acid (3-5%), and ferulic acid (0.3-5%) (Chalamacharla et al.,2018). Dietary fiber [soluble none-starch polysaccharides (sNSP)+insoluble none-starch polysaccharides (iNSP)+lignin] is resistant to enzyme hydrolysis, and wheat contains 10-12% total none-starch polysaccharides (tNSP) (Jha et al., 2019), and 19% of tNSP (=2-2.3%) is water soluble (sNSP) (Rodehutscord et al., 2016) (Table 3). Bach Knudsen (2014) reported that β-glucan (2.4), arabinoxylan (23.2), arabinose (8.5), xylose (14.7), and the arabinose/xylose ratio was (0.58% DM) in WB.

The WB contains 90% of the whole grain phenolic acid (ferulic acid) and bioactive compounds (alkylreorcinol lignin, sterols, and tocols) (Andersson et al., 2014). Phenolic acid could have an effect on nutritional properties (texture, color, and flavor) and there were 4.5μg/g ferulic acid (wet basis) and 80% of ferulic acid ester-linked to other constitutive elements of the cell wall (arabinoxylans) (Giet al., 2010).

Some bioactive compounds in WB include phytic acid (21800-52200 mg/ kg), ferulic acid (5000-15000 mg/kg), alkylreorcinos (ARs) (2200-4000 mg/kg), Lutein (970-1400 μg/ kg), iron (110 mg), zinc (73 mg), and selenium (780μg/ kg) (Chalamacharla et al., 2018). Another study stated that phytochemicals include alkylresorcinol (489-1429), phytosterols (344-2050), ferulic acid (1376-1918), bound phenolic compounds (4.7-2020), and flavonoids (3000-4300) μg/g (Onipe et al., 2015).

The lipid content in WB (5.5-5.6%) and wheat germ (28.5%) (Chalamacharla et al., 2018). In WB, 50% of the lipids are unsaturated (Kim et al., 2009). Also, Yadav et al. (2021) reported that predominant lipids in WB include triacylglycerols (41.6–53.2 wt %), followed by total free fatty acids (7.6–13.8 wt %), linoleic acid (4.5–8.4 wt %), 1,2-diacylglycerols (2.2–7.5 wt %).

The energy content analysis of WB showed that the average nitrogen corrected true metabolize energy (TMEn) was 2062 kcal/kg DM (Lotfi et al., 2019). Crude fat and crude protein have a positive effect on TMEn, whereas ash and crude fiber have a negative impact on TMEn (Janmohammadi et al., 2022). Fine WB is a good energy source (GE:19.56 MJ/kg, CP:18.1%) (Wesendonck et al., 2013). Yun et al. (2013) observed that WB energy was gross energy (GE; 18.92), net energy (NE, 3.49 -6.07) MJ/kg (26-28 days) and ME content basis on following formula: NE=2.233+0.683AME-0.050NDF (26–28 days, R2= 0.99). The calculated MLR (multiple linear regression) model to predict the TMEn value (kcal/kg) based on chemical composition (% of DM) was obtained as follows: TMEn = 2364 + (19 × crude protein) + (46.1 × crude fat) – (63 × crude fiber) – (51.1 × ash) (Janmohammadi et al., 2022).

Table 1. Proximate nutritional composition of wheat bran.

Item	Janmohammadi (2022)		NRC (1994)	Lotfi et al. (2019)		INRAE-CIRAD-AFZ (2022)		Brazil (2011)	CVB (2018)
	Mean	Max-Min	Mean	Mean	Min-Max	as fed	on DM	Mean	Mean
DM	915	928-895	890			869	1000	884	870
CP	178.9	196-151.4	157	162.3	114-206.5	153	176	156.2	155
EE	43.7	49.3-37.9	30	48	26.6-85.7	33	38	35	38
Ash	59	81.4-44.8		56.8	26.7-123	48	56	47	48
CF	80.9	116.8-51.6	110	86	47.5-126	92	105	95	106
NFE	637.5	683-587.6						550.6	
NFC	136.4	340-169.8							
ADF	147.2	180-124.6				118	135	136.4	
NDF	457.2	537.7-414				396	456	401	
Lignin						34	39		
Sugar						69	76		56
Starch						194	223	313	
Ca	1.46	2.16-0.87	1.4			1.2	1.4		1.4
P	11.46	16.91-6.17	11.5 Total			9.5	11		9.8
Na	0.33	0.6-0.19				0.07	0.08	0.2	
K	15.81	18.58-12.37	11.9			11.7	13.9	10.3	12.3
Mg	10.38	13.51-6.06				3.6	4.2		
Cl			0.6			0.8	0.9	0.6	
GE	4330	4435-4229				3930	4520	3914	
TMEn			1725	2062	1274-2496	1580 (AMEn)	1820	2119	

All units are in g/kg DM and energy (GE, TMEn) is in kcal/kg. DM (Dry matter), CP (Crude protein), EE (Ether extract), Ash (Crude ash), CF (Crude fiber), NFE (Nitrogen Free Extract), NFC (Non Fibrous Carbohydrate), ADF (Acid Detergent Fiber), NDF (Neutral Detergent Fiber), Lig (Lignin), GE (Gross energy), Ca (Calcium), P(Phosphorous), Na (Sodium), K (Potassium), Mg (Magnesium), Cl (Chlorine), LA (Linoleic acid).

Table 2. Vitamin and fatty acids of wheat bran.

Vitamins (mg/kg)	INRAE-CIRAD-AFZ (2022)		Chalamacharla et al. (2018)	Fatty acids (g/kg)	Sauvant et al. (2004)		INRAE-CIRAD-AFZ (2022)	
	as fed	DM			g/kg, as fed	% FA	as fed	DM
A (1000IU/kg)	0.09	0.1		C12:0 lauric acid			0.02	0.02
D (1000IU/kg)	0	0		C14:0 myristic acid	0	0.1	0.04	0.04
E	14.8	17	14	C16:0 palmitic acid	4.9	17.8	4.7	5.4
K	0.5	0.5		C16:1 palmitoleic acid	0.1	0.4	0.1	0.1
B1(thiamin)	7.6	8.7	5.4	C18:0 stearic acid	0.2	0.8	0.2	0.2
B2(riboflavin)	4	4.6	3.9-7.5	C18:1 oleic acid	4.2	15.2	4	4.6
B6 (pyridoxine)	9.8	11.3	10-13	C18:2 linoleic acid	15.6	56.4	14.7	17
B12 (μg/kg)	0	0		C18:3 linolenic acid	1.6	5.9	1.5	1.8
Niacin	192	221	140-180	C18:4 stearidonic acid			0	0
Pantothenic acid	28	32.3	22-39	C20:0 arachidic acid			0.05	0.06
Folic acid (μg)	0	0	790-2000	C20:1 eicosenoic acid	0.4	1.3	0.3	0.4
Biotin	0.3	0.4	0.48	C20:4 arachidonic acid			0	0
Ascorbic acid	0	0		C20:5 eicosapentaenoic acid			0	0
Choline	744	856		C22:0 behenic acid			0	0
Betaine (mg/ kg)			10000-13000	C22:1 erucic acid			0.1	0.2
				C22:5 docosapentaenoic acid			0	0
				C22:6 docosahexaenoic acid			0	0
				C24:0 lignoceric acid			0	0
				Total Fatty acids (%)		80	2.6	3

Table 3. Fiber type and NSP content from cereals (Jorge Olmos-Soto et al., 2015; Tejeda and Kim, 2021).

Dry matter, %	Carbohydrates	Wheat	Corn	Oat	Barley	Rye
	Arabinose	2.9	2.2		2.8	
Arabinoxylans	Xylose	4.7	3		5.6	
	Uronic Acid	0.4	0.7			
B-Glucans	Glucose	0.8	0.1	3.8	4.2	2
Cellulose	Glucose	2	2.2	0.6	4.3	1.3
	Mannose	0.3	0.3		0.4	
Pectin	Rhamnose					
	Galactose	0.4	0.5		0.3	
Total NSP		11.9	9.9	23.2	16.7	15.2
Insoluble NSP		9.4	8.9	19.2	12.2	11
Soluble NSP		2.5	0.9	4	4.5	4.2
Major NSP		Arabinoxylan	Arabinoxylan (AX)	B-glucans	B-Glucan	Arabinoxylan
Structure-linkages		β 1–4	β 1–4	Glu β 1–4 β-O-4	Glu β 1–4 β-O-4	β 1–4

ADVANTAGES OF WHEAT BRAN

Wheat bran contains significant amounts of protein, fat, B-vitamins, and crude fiber. Javed et al. (2012) reported that the aleurone layer of wheat bran provided 60%, 32%, and 80% of vitamin B6, thiamine and niacin, respectively. B vitamins are a class of water-soluble vitamins that are 0.091, 0.303, and 0.123 g/kg in whole grain wheat, WB, and wheat germ (Stevenson et al., 2012). Wheat bran is rich in vitamin E and carotene (Balandran-Quintana et al. 2015: USDA 2020). Group B vitamins, especially niacin, which play an important role in the body's biochemical processes, are significant in bran. Compared to germ, wheat bran contains more vitamin pyridoxine (B6) and riboflavin vitamin (B2) (Wang et al., 2019). Wheat bran is a good source of betaine. Supplementation of betaine in poultry improved performance, carcass traits, immune response, enhancement of physiological conditions (osmotic pressure), and alleviates coccidial and reduced heat stress (Attia et al., 2005; Hassan et al., 2005; Abd El-Ghany and Babazadeh, 2022). The amount of betaine in WB is 13390-15060 mg/kg (Zeisel et al., 2003), and betaine supplementation could require methyl group donors (methionine and choline) (Siljander-Rasi et al., 2003), and betaine increased nutrient digestibility (Ratriyanto et al., 2017). Somensi et al. (2019) stated that the inclusion of fine wheat bran (rich in betaine) improved FCR in broilers and did not promote methyl radical supply.

Wheat bran is rich in minerals, such as potassium, phosphorus, calcium, and magnesium (Balandran-Quintana et al. 2015: USDA 2020). Compared with wheat germ, wheat bran showed higher levels of iron (Fe, 7-9 fold), calcium, P(4-6 fold), K, Cu, Se, and Zinc (2-4 fold). The iron (essential mineral for microbes) and zinc in wheat bran sample were 134, and 83 (μg/g), and prebiotics from wheat bran significantly up-regulated ($p < 0.05$) the expression of iron and zinc metabolism-related proteins (Wang et al., 2019) (Table 4).

Due to its insoluble dietary fiber (IDF) content, wheat bran acts as a prebiotics and promotes the growth of beneficial bacteria in the digestive system. Wheat bran after fermentation in the hindgut and short-chain fatty acids (SCFA) (acetate, propionate, and butyrate) production by the microflora results in colon, which affects bulking, water retention capacity, and viscosity (Natalia et al.,2013). Short-chain fatty acids produced at the end of the digestive system of birds are an insignificant source of energy in poultry their contribution is 2-3% of daily ME (Jonsson et al., 2012). Natural prebiotics extracted from wheat bran and cellulase wheat bran showed enhanced brush border membrane (BBM) functionality, altering the gut microflora, gene expression (mineral metabolism), and number and diameter of goblet cells. Prebiotics from WB increased the *Bifidobacterium* population (Wang et al., 2019). Arabinoxylan extracted from wheat bran increases

Table 4. Different fiber source composition table (% DM basis)[1].

Feedstuffs	DM	CP	CF	ADF	NDF	EE	Ash	Ca	P	K	Cl	S	Zn	AMEn broiler	Fatty acids	Water insoluble cell walls
	%	%	%	%	%	%	%	%	%	%	%	%	ppm	kcal/kg	%	%
Barley bran	91	12	21	27	36	4.3	7									
Beet pulp dried	91	9	21	26	46	0.7	5	0.65	0.08	0.9	0.4	0.22	21	720	0.4	64.8
Corn Bran	91	11	10	17	51	6.3	3	0.04	0.15	0.1	0.13	0.08	18	2420	4	41.8
Cottonseed Hulls	90	5	48	70	87	1.8	3	0.15	0.08	1	0.02	0.05	10			
Oat Hulls	93	4	33	41	75	1.6	7	0.16	0.15	0.6	0.08	0.14	31	940	2.3	69.8
Peanut Hulls	91	7	63	65	74	1.5	5	0.2	0.07	0.9						
Rice Bran	91	14	13	18	24	16	11	0.07	1.7	1.8	0.09	0.19	40	1870	0.9	33.9
Rice Hulls	92	3	44	70	81	0.9	20	0.12	0.07	0.5	0.08	0.08	24	530	1.1	68.6
Soybean Hulls	90	13	39	48	62	2.3	5	0.6	0.19	1.3	0.02	0.12	38	2530	1.4	21.6
Sunflower Seed Hulls	90	4	52	63	73	2.2	3	0	0.11	0.2		0.19	200	700	3.3	84.4
Wheat Bran	**89**	**17**	**11**	**14**	**46**	**4.4**	**7**	**0.13**	**1.32**	**1.4**	**0.05**	**0.24**	**96**	**1820**	**3**	**44.7**

[1]Feedstuff, 2012; INRAE-CIRAD-AFZ, 2022 (3 last column).

the *Bifidobacterium* population in pigs (Nielsen et al., 2014). Vermeulen et al. (2017) found that WB with a particle size of 280 µm decreased *Salmonella* colonization.

Arabinoxylan derived from wheat bran have been shown to improve gut health (gut microbiota and digestive traits) (Akhtar et al., 2012; Eeckhaut et al., 2008). Adding 0.4% AXOS (arabinoxylooligosaccharides) could cause a significant reduction in *Salmonella Enteritidis* colonization (Eeckhaut et al., 2008).

The AXOS could increase the number of *bifidobacteria* in the cecum (directly decreasing *Salmonella* and *Bifidobacteria* and increasing butyric acid production and growth of anaerobic bacteria) (Belenguer et al., 2006).

The WB amino acid pattern was the same as that of the whole wheat (Table 5). There are 18 amino acids in WB, and a variety of amino acids in WB protein have better physiological and nutritional value than wheat protein (Maharjan et al., 2021). Wheat bran stimulates bird growth, which is probably caused by the effects of correcting or adjusting the intestinal microbial population (Hegde et al., 1978).

Wheat bran was used to dilute the rations in broiler and parent stocks to control their growth rate. The use of WB has beneficial effects on the health of the digestive system and poultry performance (Ali et al., 2008), digestibility, and microbial activity owing to the presence of compounds such as phytoestrogens, lignans, phenols, and antioxidants in WB (Martínez et al., 2015). Wheat bran can regulate gastrointestinal physiology (intestinal transit rate and gastric emptying time), and this improvement affects digestive function (De Mora Ruiz-Roso et al., 2015). The use of 0.2% *Saccharomyces cerevisiae* yeast, 10% WB, and 6% soybean husk causes an increase in daily weight and feed consumption. The increase in feed intake is due to an increase in the amount of polysaccharides in the soybean husk and WB (Daneshyar et al., 2019).

Table 5. Amino acids composition in wheat bran and wheat grain.

AA (g/kg)	INRAE-CIRAD-AFZ (2022)		NRC (1994) (as fed)			Sauvant et al. (2004)	
	as fed	DM	WB	HRW	SWW	TDC (g/kg)	TD (%)
Lysine	4.6	5.3	6.1	3.7	3.1	4.3	74
Threonine	3.5	4	5	3.9	3.2	3.5	75
Methionine	1.9	2.2	2.3	2.1	1.5	1.7	74
Cystine	2.4	2.8	3.2	3	2.2	2.4	75
Met+Cys	4.3	4.9	5.5			4	75
Tryptophan	1.5	1.8	2.3	1.6	1.2		
Isoleucine	3.9	4.4	4.7	4.4	4.2	3.6	76
Valine	5.1	5.9	7	5.7	4.4	5	75
Leucine	7.2	8.3	9.6	8.9	5.9	7.2	79
Phenylalanine	4.7	5.5	6.1			4.7	80
Tyrosine	2.9	3.3	4.6	4.3	3.9		
Phe+Tyr	7.6	8.8	10.7				
Histidine	3	3.5	4.6	3.1	2	3.1	82
Arginine	7.6	8.7	10.2	6	4	7.6	84
Alanine	5	5.8		6	4.5		
Aspartic acid	7.5	8.6					
Glutamic acid	26.6	30.6					
Glycine	5.3	6.1	8.1	5.9	4.9		
Serine	4.9	5.7	6.7	5.9	5.5		
Proline	7.9	9					

Lysine, ileal standardized (poultry). WB: wheat bran. Grain of wheat hard red winter (HRW), wheat grain soft white winter (SWW).

One of the beneficial effects of WB and germ is the presence of phenolic compounds and antioxidants (Beta et al. 2005). The higher antioxidant potential of WB is related to the concentration of secondary metabolites (flavonoids, phytosterols, and mainly phenolic acids) (Singh et al., 2012). Phenolic compounds act as inhibitors of the effects of enzymes (Tome et al.,2004) and have antioxidant properties that maintain gut hemostasis in *in vitro* tests (Kim et al.,2006). Phenolic acids are divided into hydroxybenzoic and hydroxycinnamic acids, and 85% of the total phenolic acids in WB are related to hydroxycinnamic acid and ferulic acid (e et al.,2014; Kim et al., 2016). Ferulic acid (acts as an antioxidant, increases blood flow, and induces arterial vasodilation) (Tang et al., 2021). The physical structure of WB affects its antioxidant capacity (Noort et al. 2010). In addition, other WB compounds, such as alkylresorcinol (reduction of colon cancer cell growth) (Prückler et al. 2014), phytosterols, and tocopherols (which inhibit cholesterol absorption) (Onipe et al., 2015). Wheat bran nutrition for humans decreased (heart attack, type 2 diabetes, obesity, defecation time or intestinal transit, cancer of the colon, anus, prostate, and ovary) and increased (immunity against viruses, fecal bulk or laxative effect, and satiety) (Figure 4).

These effects are related to two insoluble dietary fiber characteristics (water swelling capacity and water retention capacity) (Wuet al., 2012; Galisteo et al., 2008). Consumption of 40 g/day of WB (compared to rice bran) significantly reduces total cholesterol and LDL levels in the blood serum of women with hypercholesterolemia (the most important cause of cardiovascular disease) (Matani et al., 2006). In addition, administration of 12 g of WB for three weeks in food for diabetics decreased the level of LDL in the blood and increased the level of HDL (Noorian et al., 2002). It is necessary to conduct comparative studies on the positive effects of different types of fiber sources on birds with cardiovascular disorders. Soluble dietary fiber (SDF) reduces the glycemic response (cardiovascular risk), plasma cholesterol (diabetes type 2 and disease), and improves the intestinal flora (Prückler et al., 2014).

CHALLENGES OF WHEAT BRAN

Increasing the proportion of cereal (wheat) and ceral-co-product (wheat bran) in the poultry diet increases the amount of β-glucan and arabinoxylan (pentosans) (the main NSP of wheat), and as a result, increases the viscosity of the gut content (Silversides et al., 2006), microbial population, fermentation of nutrients, and production of volatile fatty acids, and finally reduces the acidity of the gut contents (Shakouri et al., 2006; Thiabalut et al., 1993; Weber et al., 1993; Finnie et al.2006). These changes reduce the effects of digestive enzymes and the level of absorption, and as a result, decrease digestion and absorption of nutrients (Choct et al., 1999). Most arabinoxylan molecules are insoluble. The soluble/insoluble ratio in Arabidopsis is flexible and dependent on the xylose and arabinose subunit ratio (Chalamacharla et al., 2018). The arabinose/xylose (A/X) ratio varies from 0.3 to 1.1 for different WB sources (Kaur et al., 2019). The dietary sNSP/tNSP ratio in poultry formulations is important. Nguyen

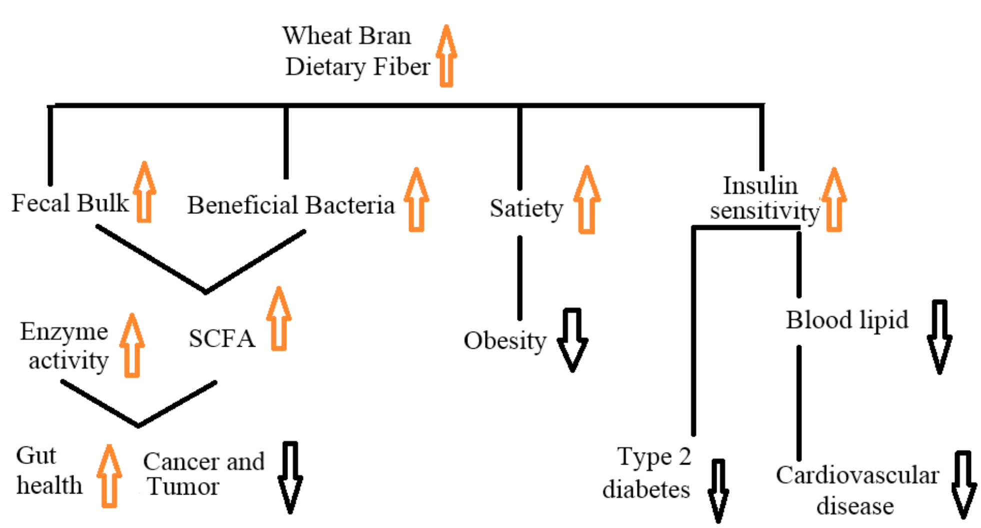

Figure 4. Main advantages of wheat bran feeding.

et al. (2022) reported sNSP, iNSP, and tNSP (totalNSP=sNSP+ iNSP) in wheat (14.2, 83.0, 97.3), corn (2.86, 64.50, 67.4), barley (42.3, 137.4, 180), wheat bran (23, 385, 408) and soybean meal (11.2, 132, 143.4) g/ kg and sNSP/tNSP ratio were 0.146, 0.042, 0.235, 0.056, 0.078 respectively. Musigwa et al. (2021) reported that sNSP, iNSP, tNSP and sNSP/tNSP ratio in broiler starter (36.1, 92.8, 129 g/kg, 0.280) and grower (31.4, 90.2, 122 g/kg, 0.259). Dietary fiber improved goblet cell numbers and MUC2 gene expression (Mucin2), and soluble fiber viscosity affected both goblet cell number and small intestine mucin secretion in rats (Ito et al., 2009).

The presence of anti-nutritional compounds, such as phytic acid and tannin, in wheat bran has been reported (Kumar et al., 2010) (Table 6). Phytic acid in maize (0.7-2.2%), wheat bran (2.1-7.3%) (Schlemmer et al., 2009), and wheat grain, bran, and germ are 9 g/kg, 42 g/kg, and 18 g/kg, respectively (Stevenson et al., 2012). Approximately 90% of phytic acid is present in the aleurone layer (Lopez et al. 2002), and the amount of phytic acid in grains is approximately 1-2% of grain weight (Febles et al., 2001). The presence of 5.4-8.4% phytic acid in wheat bran limits the consumption of this substance (Javed et al., 2012) and reduces the bioavailability of

Table 6. Anti-nutritional factors in wheat.

Anti-nutrient	Main effects
Phytic acid (Phytate)	• Phosphorous(Phytate) are not bioavailable for monogastrics and excreted P caused water and soil pollution. • strong bind to metallic cations (K, Mn, Mg, Ca, Fe, Zn) and reduce micronutrient bioavailability • As anti-carcinogenic agent (breast, prostate, colon cancer) with un-known mechanism. • Level of phytate in wheat 9-26.3mg/ kg (Ram, 2020)
Protease inhibitors (PIs)	• Small molecules, inhibit protease activity. • Effects on trypsin inhibitor (TIs) and caused gastric anguish, pancreatic hypertrophy (Horton et al., 2006) • PIs are 4 families (cysteine PIs, metalloid PIs, aspartic PIs, and serine PIs)
Trypsin inhibitor (TIs)	• Cereals are sources of trypsin and chymotrypsin inhibitors. • trypsin inhibitory activity (TIA) of rye is ten folds more than wheat and oats. • TIs caused to pancreatic hypertrophy and increased pancreatic secretion. • Digestibility and excretion of N in the feces (Gilani et al., 2005). • Reduced protein and amino acid and reduce N and sulfur absorption (need to methionine and cysteine increase) • Stimulation of trypsin and chymotrypsin secretion from the pancreas.
Tannins	• Precipitate proteins, inhibit digestive enzymes and affect the utilization of vitamins and minerals. • Tannins concentrated in seed coat. Tannins in wheat (0.4), maize (0.4), barley (0.7) (Juliano, 1985). • Decrease feed intake, feed efficiency, growth rate, protein digestibility and poultry health. • High tannins caused depressor microbial enzyme activity (Aletor, 2005). • Phenolic groups of tannins bind to proteins very tightly.
Cyanogenic glycosides (CG)	• Variety, age of plant and environmental condition are important in level of CG.
Alkaloids	• Generally produced from tyrosine, tryptophan, and lysine. • More than 12,000 alkaloids, 150 families, were recognized (Ram, 2020)
Lectins	• Lectins are proteins that bind to a specific carbohydrate reversibly without altering their structure. • As hemagglutinins owing to its capability to bind and agglutinate RBCs (red blood cells • lectins in five main groups (mannose, galactose, N-acetylglucosamine, fructose, and sialic acid).
Oxalate	• Oxalates level in wheat (0.442%), barley (0.325), rice bran (0.445%) (Ram, 2020) • Total oxalate was 3930mg in wheat bran flask and 379 mg/kg DM

cations (Ca, Mg, Fe, Zn, Mn) (Waters et al. 2015). Administration of phytase and fungal amylase along with reducing the particle size of wheat bran to 280 µm (Penella et al., 2008) and hydrothermal processes (after reducing the particle size to 90 µm) reduce phytic acid by 90% (Majzoobi et al.,2014). The other anti-nutritional in wheat bran is tannin which in coarse, medium and fine non-fermented wheat bran are 0.03, 0.06 and 0.07 mg catechin/100gm material (Hassan et al., 2008).

The high lignocellulosic content (44%) of WB, low ME (1300 kcal/kg), and the presence of NSP make it an unsuitable source for monogastric animals (Prückler et al., 2014). Administration of NSP (wheat and WB) decreases villi height and Lactobacillus and Bifidobacteria populations, and increases ileum crypt depth and the population of gram-negative bacteria (Coliform and Clostridium) (Yaghobfar et al., 2015).

Water-soluble NSPs (increased viscosity) or insufficient fiber increased the secretion of bile acids (deoxycholic acid, cholic acid, and alloavicholic acid), and binding to bile salts decreased fat digestibility and metabolism (Smith et al., 1997) and increased the excretion of fat in the feces (Mateos et al., 2012). The addition of adequate insoluble fiber, enzymes, bile salts, or bile acids is one way to reduce its negative effects. Supplementation with wheat bran plays an important role in lipid metabolism (metabolic regulation) in rats and humans (Jenkins et al., 2014; Jenkins et al., 2020). A meta-analysis by Ghavami et al. (2023) showed that supplementation of soluble fiber in adult humans could manage dyslipidemia and reduce the risk of cardiovascular disease.

One of the serious challenges in poultry nutrition is the presence of aflatoxin, which affects immunity, health, and performance, and should not be neglected in the measurement and control of poultry feed, especially cereal bran. The tested samples that were contaminated with aflatoxin B1 were in fish meal (100%), soybean meal (92%), wheat (88%), and corn samples (16%) (Mayahiet al., 2007). The level of aflatoxin B1 in poultry feed in one of the cities in Iran (Sanandaj) was high, and 47% of the samples were higher than the standard limit (10µg/kg). And contamination between 6.4 (autumn) and 18.3 µg/kg (winter) (average 10.5 µg/kg) (Mohammadi et al., 2021) (Table 7).

FERMENTED WHEAT BRAN

The manuscripts available on the PubMed website show that, in poultry nutrition, the first research on wheat bran (WB) and fermented WB (FWB) dates back to Wang et al. (2017), and research in this field has grown substantially since 2020. In addition to enhancing nutritional value, the fermentation process contributes to the development of functional feeds that significantly benefit broiler health. Recent advancements have demonstrated that fermented feeds contain essential functional ingredients such as lactic acid bacteria (LAB), lactic acid, and various organic acids. These components are crucial for improving the gut health and overall performance of broilers. The presence of LAB and organic acids in fermented feeds helps to establish a healthy gut microflora, reduce pathogenic bacteria, and boost the immune system of broilers, thereby leading to better growth rates, feed conversion ratios, and overall productivity. The ongoing research emphasizes the potential of fermented feed to offer a cost-effective and efficient solution for enhancing poultry nutrition and health (Sugiharto and Ranjitkar, 2019).

The reduction of fiber content in wheat bran is achieved by different physical and chemical methods (generally high cost, e.g., ultra-fine grinding, extrusion, ultra-high pressure), microbial fermentation, and yeast culture. Filamentous fungi (*Trichoderma spp*.) are the main source of cellulose (Cherry and Fidantsef, 2003) and are suitable for lignocellulosic material fermentation. Fermentation of wheat bran (with fungi or bacteria) leads to improvement in nutritional properties, increase in the number of lactic acid bacteria, organic acid concentration, and decrease in pH. Fermentation of WB increased phenolic acids and polysaccharides (Zhang et al., 2014). Recent study of (Li et al., 2022) highlight the potential of solid-state fermentation (SSF) using medicinal fungi namely Isaria cicadae Miq., Cordyceps militaris, and Inonotus obliquus as a promising approach for the valorization of wheat bran, leading to the development of functional whole grain foods with improved nutritional and sensory characteristics. Solid-state fermentation (SSF) of wheat bran. significantly enhanced the nutritional properties of wheat bran, including the extraction yield of soluble dietary fiber (SDF), total phenolic content (TPC), total flavonoid content (TFC), swelling capacity (SC), oil absorption capacity (OAC), and antioxidant activities. Notably, each of the three fungi exhibited distinct fermentation characteristics, Furthermore, the fermented wheat bran samples exhibited different volatile profiles compared to unfermented wheat bran, as evidenced by electronic nose and GC–MS analyses.

Table 7. Acceptable limit for nutrients, heavy metals, fungal and microbial characteristics of raw wheat bran.

Item	Unit	INSO	EAC	
			Bran	Pollard
Moisture	%	max 12	12	12
Fat	%	1.5-4	2.5	2.5
Crude protein	%	min 11	13.5-15	12
pH		6-6.5		
Crude fiber	%	9-11	12	8
Total ash	%	5.5-6.5	1	5
Acid insoluble ash	%	max 0.1	0.5	0.5
Particle size		90% lower than 250 micron		
Total count microorganism	N/g	10^3		
E. coli	N/g	0		
Mold	N/g	10^2		
Pb	ppm	max 0.15		
Cd	ppm	max 0.03		
Aflatoxin B_1	ppb	5		
Total Aflatoxin	ppb	15	<20	
Ochratoxin A	ppb	5		
Zearalenone	ppb	200		
Deoxynivalenol	ppb	1000		

Iranian national standardization organization (INSO), East African communication (EAC).

The aim of wheat bran fermentation is to reduce anti-nutrients while maintaining the quality of wheat bran with *Lactobacillus plantarum* bacteria and *Saccharomyces cerevisiae* yeast, which in the case of *L. plantarum* shows a 95% decrease in phytic acid (at 35°C for 9.5 h) in an anaerobic incubator (Moshref et al., 2014).

The hypothesis of increased nutrients in fermented wheat bran compared to raw wheat bran has led to further research in this field. Inclusion of 10% FWB by *Trichoderma longibrachiatum* (cellulase-secreting fungi) had better performance and FCR without negative effects on the histological structure of the blood parameters (Elmasry et al., 2017). Previously, Chiang et al.(2010) observed that a product (75% rapeseed, 24% wheat bran, and 1% brown sugar) fermented by a mix of (*Lactobacillus fermentum, Enterococcus faecium, Saccharomyces cerevisiae,* and *Bacillus subtilis*) (xylanase-producing) augmented lactobacilli counts (in colon and ceca digesta), villus height and VH/CD (in ileum and jejunum), performance, and intestinal morphology of broilers. Supplementation with FWB and yeast culture (YC) increased immune levels, intestinal development and barrier, intestinal flora and intestinal microbial community stability, better growth, and decreased bacterial diversity (FWB and YC together) in pigs (He et al., 2021). In the livestock industry, employing Solid-State Fermentation (SSF) to enhance agro-industrial waste for producing protein-rich animal feed helps diminish anti-nutritional components that typically impede nutrient digestibility and availability in such wastes. Consequently, SSF application enhances the nutrient composition and quality of repurposed agro-industrial waste as animal feed. This approach to fermented feed production can potentially offer safer, cost-effective options and contribute to improved growth performance and animal health (Levi et al., 2023).

Recently, Zhang et al. (2022) reported that solid-state fermented FWB is a suitable feed component for broilers, and inclusion of FWB at 25 or 50 g/kg in broiler rations had no influence on the performance and apparent nutrient digestibility of the feed and AME(1854) and AMEn (1744 kcal/kg of DM) for broilers. Also, FWB composition compared with WB was: CP (16.6, 18.5%), starch (7.3, 6.2%), CF(8.8, 7.2%), pH (6.7, 4.7), crude ash (5.3, 4), NDF (36.3, 28.9), ADF (10.2, 9.8%), EE (3.2, 1.9%), total acid (0.1, 45.1 mg/g) and GE (3986, 3786 kcal/kg). In another study, Wang et al. (2017) found that FWB (fermented by *Pleurotus eryngii*) could increase lignocellulolytic enzyme activities, and the levels of active components can potentially elicit the Nrf2/ARE antioxidant pathway (nuclear factor erythroid-2-related factor 2/ antioxidant response element), thereby decreasing lipid peroxidation without negative effects on broiler performance.

The beneficial effects of FWB on microflora showed that 5% FWB (*Bacillus cereus*) duodenal amylase was 1.56 times more than the control group, and the Chao1 index of microbiota (total number of species in a sample) in the cecum increased by 24.2% (Feng et al., 2020). Lin and Lee (2020) reported that 5% administration of *Laetiporus sulphureus*–FWB had significantly higher BW, FCR, lower coliform counts in ileum, increased serum IgA, lower liver and jejunum IL-1β and NF-κB mRNA. Furthermore, research has indicated that the fermentation process can modify the volatile compounds present in wheat bran, resulting in changes in aroma profiles that have the potential to enhance food flavors. This indicates that fermented wheat bran fiber not only provides nutritional advantages but also has the ability to enhance the sensory qualities of food products.

In general, further exploration is necessary to optimize the type, form, and quantity of fiber included in poultry diets to ensure optimal performance and economic advantages under commercial circumstances. Additionally, more research is required to uncover the underlying mechanisms through which different types of fibers impact gut health in poultry. Given the growing interest in incorporating dietary fiber into poultry nutrition and its potential economic and environmental benefits, continued investigation into the fermentation of wheat bran fiber is justified (Jha and Mishra 2021)

WHEAT BRAN IN PELLETED AND MASH RATION

Despite the use of pellet feed in 1927 and laying rations since 1945, the reception of pellet rations in broilers and layers (especially during the rearing period) has increased; however, the mash diet is still dominant in laying and parent stocks. The use of pellet ratios decreased the proportion of coarse particles in the feed. Choosing a mash feed with enzymes is a strategy to supply fiber and exploit its positive effects on the gizzard. These strategies can increase the secretion of hydrochloric acid and bile acids (Svihus, 2011) and improve growth performance (Gonzalez-Alvarado et al., 2008). In addition, coarse particles remain in the gizzard for a longer time than fine particles, increase the motility of the digestive system, increase the reflux of digestive substances from the duodenum to the gizzard, and improve the digestibility of nutrients (Rogel et al., 1987). Organ weight is a very important issue in the addition of wheat bran and other fiber sources to the diet of broiler chickens and other poultry.

The first research on steam pelleting of WB was conducted by Shyam Sunder and Jensen (1978) and inclusion of 10-30% in ration resulted in better final body weight, FCR, and lower water consumption. Steam pellets increased WB energy by 10% and improved available phosphorus by 20%. Low ME, high density, and high fiber content are among the most important characteristics of WB (Leeson and Summers, 2009). A wheat-based diet with mash had significantly higher gizzard mass than those fed the pelleted diet (Ahmed et al., 2007). Supplementation with moderate levels of WB (30 g/kg) as an insoluble fiber source improves gizzard development, intestinal digestive enzyme activity (amylase and trypsin in the pancreas and jejunal mucosa), morphology, nutrient digestibility, and FCR in broilers (Shang et al., 2020). Different fiber feeding in pellet could improve performance in starters and could reduce coliforms and *E. coli* in broiler cecum in pellets and mash (Boazar et al., 2021).

Rice bran (insoluble fiber) addition to pellet rations and its removal in 24 days caused a sharp increase in chicken mortality, which was due to a large increase in feed consumption, therefore, it was necessary to maintain the fiber level until the end of the rearing period (Bani Bugari, 2020). Recently, Afranji et al. (2022) investigated that physical form of feed (pellet and mash) and insoluble fiber (4% sunflower hull) suggested pellet form in Hy-line W36 only in the first 8 weeks of rearing for better performance and mash form had higher gizzard weight and increased egg yolk color compared to pellet feed. Also, Rezaei et al. (2018) observed that 1.5% wheat fiber decreased relative weight of the liver in quail. A comparison of WB and sunflower husks showed that the pellet form caused an increase in the height of the duodenal villi and the diameter of the jejunum villi compared to the mash (Boazar et al., 2022). However, comprehensive research has not been conducted regarding the comparison of the effects of WB in pellet diet and mash diet, particle size, and different levels of consumption in poultry.

WHEAT BRAN IN BROILER NUTRITION

A high amount of NSP in poultry could have an effect on poultry performance, because of poultry do not have enough enzymes to digest β 1–4, β 1–3, and β 1–6 linkages in NSP, for better efficiency in nutrient utilization, usually 2-3% of crude fiber have been proposed (Choct, 2015). Tejeda and Kim (2021) suggested insoluble fibers (cellulose, lignin, and arabinoxylans) (>1.5 mm) could improve digestive organ weight and nutrient digestibility. The size of the fiber particles (fine:1 and coarse: 3mm) caused a significant increase in the weight of the chickens caecum (without effect on gizzard weight) using 3% of insoluble fiber (sunflower, rice and camelina hulls) was reported by Jamshidi and Moradi (2020). Research on the effects of different fiber types on nutrient digestibility has mostly focused on oat hulls, and research on WB is very exceptional. The use of xylanase in the diet of broiler chickens containing 25% WB has been reported to increase protein digestion and absorption (Pourreza and Classen, 2001).

The best level of WB in broiler diets to reach maximum performance (with multiple enzymes) is recommended to be 4% (Idan et al., 2023). The use of 7.5% WB with phytase enzyme has no significant effect on the performance and carcass traits of broiler chickens (Ahani, 2012). Shang et al. (2020) proved this in their research, adding 3% WB increased gizzard and small intestine weight, pancreatic amylase and trypsin activity. The use of WB up to 20% of the ration of a broiler decreased feed intake, weight gain and FCR, but adding enzymes to the ration solved these problems (Daymeh et al., 2013). Supplementation with 30 % WB in broilers has no adverse effects on performance but also increases the levels of antioxidants, phosphorus, and blood globulin (Ali et al., 2008). In addition, dietary 3% WB improves antioxidant status (decreased malondialdehyde and increased glutathione peroxidase on days 21 and 42) and increased superoxide dismutase activity on day 42 (Shang et al., 2020).

High levels of fiber in broiler diets increase villus growth and reduce harmful bacteria in the intestinal epithelium (Bi and Chiou, 1996). Adding 0.5-1% inulin (increases *bifidobacteria* and decreases cecal *E. coli*) (Nabizadeh et al., 2012), 6-8% wheat, and DDG mixing increased some bacteria populations in broilers (Walugembe et al., 2015); however, these studies cannot sufficiently prove the effects of WB on the intestinal microflora and cecum of poultry. In addition, previous studies have shown that Inulin and WB enhanced the abundance of Lactobacillus and Bifidobacterium (Nabizadeh, 2012; Cortin et al., 2008) and improved the intestinal barrier (Chenet al., 2017; Wu et al., 2017). But now the difference between treatment on gene expression of Mucin2, Occludin, Claudin-1 in jejunum or ileum. However, studies in pigs and humans have revealed that adding WB and inulin changed tight junctions or mucus proteins, affecting the epithelial barrier function (Chen et al., 2017; Wu et al., 2017).

The effects of WB on digestive histomorphology of birds have also been investigated. Li et al.(2018) study scrutinized combination of 2% inulin and 10% of WB in broiler starter (synergism of two product) ameliorated gut morphology (villi height in jejunum and ileum and VL/CD in jejunum) and microbiota profile. Rezaei et al. (2018) showed that 1.5% of wheat fiber in quail increased villi: crypt ration in three section of small intestine. In addition, 1.5% micronized wheat fiber could increase the villi height and V/C ratio in geese (Chiou et al., 1996). According to An et al.,(2022), the addition of fermented wheat bran to poultry feed has demonstrated encouraging outcomes in enhancing poultry health and development. Research has shown that supplementing broiler diets with 5% dry fermented wheat bran (FWB) can boost growth performance by increasing Lactobacillus levels in the ileum and maintaining a favorable intestinal environment. Through fermentation, the water extractable arabinoxylan content, soluble dietary fiber, and total free phenolic compounds are elevated, while phytic acid is degraded. This enhancement in nutritional value contributes to improved nutrient digestibility and anti-inflammatory effects in broiler chickens

Moreover, incorporating fermented wheat bran has been linked to lower feed costs per kilogram of live weight gain compared to traditional additives like antibiotics. The inclusion of fermented wheat bran by *Bacillus* and *Saccharomyces* species has resulted in higher growth rates and improved feed conversion ratios in broilers. Additionally, studies have demonstrated that broilers consuming wheat bran fermented by *Cunninghamella* species show improved meat quality and better overall health markers.

An, J., Shi et al., 2022 conclude that incorporating 7% dry or wet fermented wheat bran (FWB) into the basal diet notably enhanced the growth performance and bolstered the serum immune performance of broilers, effectively alleviating the damage induced by LPS challenges. Furthermore, wet fermented wheat bran (FWB) demonstrated a greater potential for immunomodulation in broilers.

The advantages for poultry health and growth from integrating fermented wheat bran into their diets are considerable. The fermentation process boosts the availability of crucial nutrients, fosters a balanced gut microbiota, and bolsters immune function in poultry. By utilizing fermented wheat bran as a feed supplement, poultry producers have the potential to enhance the general well-being and performance of their flocks. (Sugiharto and Ranjitkar, 2019; An et al., 2022; Ahmad et al., 2023).

WHEAT BRAN IN LAYER NUTRITION

Poultry nutritionists usually recommend that the maximum levels of WB consumption for layers and broilers should be 15 and 10%, respectively. The Hy-line W36 management guide (2019) recommended a dietary fiber increase of 5-6% beginning with a developer diet (flock weight 950–970 g) to increase crop, gizzard, and intestinal capacity and development. Corzo and Silva (2020) recommended an important issue in which serious attention should be paid to dietary tryptophan in Ross 308 parent stock pullets when administration of WB or middling above 15%. The tryptophan/lysine ratio in wheat byproducts is between 1.5-1.8% and the level of digestible tryptophan must be higher than 0.17% to prevent feather licking and feather pecking.

The use of WB up to 15% of the diet of laying hens has no negative effects on their performance (Darmani Koohi et al., 2010). The use of 10% WB in low-phosphorus diets, along with phytase enzymes, resulted in better performance of laying hens (Yao et al., 2007). In addition, Oftade et al. (2013) reported that diets containing 10 and 20% WB had the highest and lowest egg production, and daily feed intake decreased by 20%, while other characteristics were not significantly affected by WB. In another study, the use of 10% WB in the Hy-Line W36 diet improved egg weight, egg production percentage, egg mass, feed conversion ratio, and yolk color index, while there was no significant effect on feed intake, biochemical parameters, and blood metabolites (Hoseinifard and Nobakht, 2014). Supplementation of laying ducks with WB (10.2 and 30 %) decreased egg yolk cholesterol (hypocholesterolemic effect of fiber or suppression of lipolysis in the liver) and had no effect on egg production and FCR (Pantay et al., 2020). Administration of 6% (starter) and 8% (finisher) WB and DDGS (dried distillers grains with solubles) showed that the SCFA (acetic, propionic) concentration in broiler cecum was higher than that in layer chicks (Walugemb et al., 2015).

The strategy of using insoluble fiber to reduce infections (Clostridium), mortality, and abnormal behaviors (consumption of bedding and feather pecking) can be clearly seen in laying hens. The level of β-glucan in WB is 2.4% of that in DM (Bach Knudsen, 2014). β-glucan is one of the growth promoter or antibiotic alternatives in poultry. Administration of β-glucan (200 mg/kg) during the growth period improves egg production, digestibility, blood parameters, and immune response (Ezzat et al., 2024).

When wheat or WB is used in poultry diets, feed formulators should evaluate the fatty acid profiles of the diets. NSP increases the viscosity of the ileum, its relationship with fat digestibility and absorption, and its effects on AME in layers. It is necessary for poultry nutritionists to slightly increase the amount or level of lipases and proteases. One of the most important factors in layer production with WB is that WB is a High-P and low-Ca (4/1, P/Ca ratio), and feeding more WB causes thin-shelled eggs and urolithiasis in male animals.

WHEAT BRAN AND EXOGENOUS ENZYMES

The cereal bran cell wall (CBCW) is a rich source of phenolic acids and bioactive compounds (NSP, dietary fiber, antioxidant) (Saeed et al., 2021), and the cell wall contents in wheat (41.53), maize bran (37.3), and oat bran (43.3%) (Hussain et al., 2022). Adding WB to poultry diets reduces density and causes dilution of rations. Low-density diet (LDD) affects the performance of birds, endogenous enzymes, and the requirement of exogenous enzymes. However, this issue has not been clearly stated in previous research. Inclusion of WB stimulates the secretion of enzymes by regulating hormone production (cholecystokinin and gastrin) (Hovius, 2011; Walker, et al.,2024), and administration of fructooligosaccharide (FOS) increases the bacterial population (*Bifidobacterium* and *Lactobacillus*) (inhibited *E. coli*) in the small intestine and cecal digesta and the activity of amylase (with 2 g/kg FOS) and protease (with 4 g/kg FOS) (Xu et al., 2003). Recently, Attia et al. (2022) reported that a low-density diet (with 10% WB) decreased BWG by 5.7% (117 g in 38 days), nitrogen free extract (NFE) (0.7%), increased physical traits of meat (thigh color) and chemical composition of meat and type of dietary could cause an increase in the length of intestine, relative weights of body organs compared with standard ration. Ketaren (2006) reported that the optimal and economical level of WB (pellet) to be included in broiler chicken diet was 30% with 0.02% enzyme. Multi-enzyme supplementation stimulated starch analysis, cell walls, and endogenous protein (He et al., 2022), and reduced the negative effects of NSP, oligosaccharides, and phytic acid (Gracia et al., 2003; Zanella et al., 1999). In addition, fortification with 0.2% per kg of multi-enzyme (Galzym®) in a low-density diet significantly enhances BWG (235 g; 12.7%) (Attia et al., 2022). Taheri et al. (2016) reported that supplementation with 500 mg/kg multi-enzyme (Rovabio Excel® 10%) had significant effects on FCR (1.85) compared with barley based diets (2.03), but did not differ between treatments containing different levels of WB (4,8, 12%). In addition, lower levels of WB in a barley-based diet could have a positive effect on FCR, whereas serum cholesterol and villus height were influenced by the inclusion of the highest WB level. The positive effects of bran or hulls are usually explained by factors such as increased feed passage rate in the distal section of the gastrointestinal tract (Rogel et al. 1987), absorption of a large amount of water, maintenance of normal gut motility (Stephen and Cummings, 1979), pancreatic secretion (Hetland et al., 2003), and hydrochloric secretion of the gizzard and proventriculus (Svihus, 2011).

Corn and soybean meal contain 6.83 and 16.5% tNSP (Rostango et al., 2017), and WB contains 43-60% (NSP), 11-24% starch, 14-20% protein, 3-4% lipid, 3-8% mineral (Sztupecki et al., 2023). Antinutritional factors (phytate, xylan, and β-glucan) can inhibit digestion and absorption of trace elements, and supplementation with phytase (Cu, Zn), xylanase (Cu, Zn, and Mn), and β-glucanase (Cu, Fe, and Mn) improves the release rate of trace elements (Yu et al., 2018). Phytase enhances Fe and Mg in tibia (Pintar et al., 2005; Zubair-ul-Hassan et al., 2024), Zn in tibia (Shelton and Southern, 2006), Zn utilization in poultry (Swiatkiewicz et al., 2001; Attia et al., 2019), and retention of Ca, P, Mg, and Zn (Viveros et al., 2002). The addition of phytase or β-glucanase improves bone breaking strength (change in bone matrix rather than mineralization) (Al-Qahtani et al., 2021). Excessive enzyme levels have negative effects on health (Cowieson et al., 2006), and supplementation with NSP and 160 mg/kg protease significantly decreased pancreatic trypsin mRNA (Yuan et al., 2017).

WHEAT BRAN AND ENDOGENOUS ENZYMES

Monogastric specis cannot produce enzymes such as β-glucanases, pentosanases and phytases; instead, they can produce proteases, lipases, and amylases. Approximately 65% of carbohydrates are efficiently digested because of the lack of specific enzymes that NSP is not digested and fermented by hindgut bacteria. Therefore, enzymes such as carbohydrase (amylase, ß-glucanases (cellulase), and xylanase), glucanases, proteases, lipases, phytases, and galactosidases, as well as multicarbohydrases, have been added to poultry feed for years (Attia et al., 2020). The exogenous enzymes, their substrates, and the benefits of using enzymes in poultry are shown in Figure 5.

Many factors, such as feed texture, anti-nutrients (NSP), stress and diseases, bird age, diet type, target substrate, and exogenous enzymes, could affect the amount of endogenous enzymes and their activity. The effects of adding insoluble and soluble fibers on endogenous enzymes are shown in Table 8. Intestinal viscosity was negative for endogenous β-glucanase and lipase activity (Fuente et al., 1998). Improvements in genetic selection of strains caused endogenous changes in poultry, but the extent of these changes and the extent to which each enzyme has changed is not known to us. Therefore, it is essential to run further research on precise nutrition in poultry.

The addition of exogenous enzymes increases endogenous substances in the GI tract of chickens (Krogdahl et al., 1989; Nitsan et al., 1991). Nutrient levels affect the regulation of endogenous expression of digestive enzymes (Yuan et al., 2017), and exogenous enzymes could improve FCR, BWG, AME, ileal digestibility of AA, and nitrogen retention (Ghazi et al., 2002). There is an unanswered question, that is, with the increase in different levels of wheat bran, in different poultry strains, and in different stages of rearing and production, how will the amount of endogenous enzyme change, and what is the optimal dose of exogenous enzyme? Previous research has shown that increased fat (from 3 to 30%) causes increased lipase expression 2.2-3.9 times (Wicker et

Enzymes	Feedstuff	Substrate
Xylanase	Wheat, Rice bran, Triticale, Barley, Rye	Arabinoxylan
β-Glucanase	Barley, Oat, Rye	β-Glucan
α-Galactosidase	Plants feedstuffs	Oligosaccharides(raffinose)
Phytase	Plants feedstuffs	Phytate
Protease	Wheat by- product, Legume proteins	Protein and AFNs
Lipase	Vegetable and Animal fats	Lipids
Amylase	Cereals with high starch	Starch

Enzymes Benefits	
Digestion and absorption fat andprotein	↑
Size gastrointestinal tracts	↓
Alter Micobiota	↑
Water intake, Excreta	↓
Digesta viscosity	↓
Feed intake, wight gain	↑
AME	↑
FCR	

Figure 5. Exogenous enzymes, substrates and benefits of using enzymes in poultry.

Table 8. Effects of wheat bran, insoluble and soluble fiber on digestive enzyme activities.

Item	Effects	References
30 g/kg WB	Increased amylase and trypsin in pancreas and jejunal mucosa On Day 21, 42(improved nutrient digestibility)	Shang et al. (2020)
Insoluble fiber (1% Arbocel RC)	• At wk 5, proventriculus pepsin and GP activity greater than control. • At wk 10, activities of pepsin, GP, trypsin and chymotrypsin significantly greater than other.	Yokhana et al. (2015)
2% sugarcane bagasse (SB) Coarsely ground corn (CC)(3576 μm)	• 2% SB upregulated pancreatic amylase (AMY2A) and intestinal (CAT1). • CC upregulated duodenal APN. • SB or CC in a pelleted diet is upregulation of genes encoding digestive enzymes and nutrient transporters. • combination of CC and SB was more beneficial for the upregulation of PGA5 and PGC genes.	Kheravii et al. (2018c)
Arbocel BWW-40 cellulose	Activity of trypsin and chymotrypsin(proteolytic) in the pancreas higher than the control.	Bogułsawska-Tryk (2005)
200 g/kg Enzyme (Allzyme PT) and WB (17%)	At 7 wk, Body weight 5.8% higher, FCR improvement 21.1%	Osei and Oduro (2000)
NSP enzyme and NSP enzyme combined with 40 or 80 mg/kg protease	Increased the activity of pancreatic trypsin by 74.13%, 70.66% and 42.59% on 21 days. NSP enzyme and NSP enzyme + 40 mg/kg protease increased the activity of pancreatic trypsin by 32.45% and 27.41% on 42 days.	Yuan et al. (2017)

Pancreatic general proteolytic(GP), cholecystokinin (CCK), Aminopeptidase N (APN), pancreatic alpha 2A amylase (AMY2A), cationic amino acid transporter-1 (CAT1), pepsinogen A (PGA5), pepsinogen C (PGC), wheat bran (WB) al., 1988). An increase in carbohydrate (11 to 75%) caused an increase 3.5-8 times in pancreatic amylase mRNA (Giorgi et al., 1984). Another study reported that when protein levels increased (from 15 to 70% in rats), increased chymotrypsin (3.9), pancreatic trypsin (3.6), and elastase expression (1.8 times) (Giorgi et al., 1985).

The super dose level of phytase increased pancreatic protein content and chymotrypsin and decreased lipase activity on day 10; however, on day 24, chymotrypsin activity was reduced and lipase, GPA (general proteolytic activity), and total protein content increased (Al-Qahtani et al., 2021). High phytase supplementation causes an increase in jejunal enzyme activities (Al-Qahtani et al., 2021), and this effect is related to the increase in jejunal alkaline phosphatase and dephosphorylation of myo-inositol monophosphate (IP1) (Yusoff et al., 2011).

WHEAT BRAN AND ENDOGENOUS PHYTASE

The (phytate) content in plant (cereal, oil seed, legume) seeds is approximately 1-3% of the dry weight (Graf, 1983). Wheat, WB, wheat germ contains phytate 0.39-1.35, 2.1-7.3, 1.14-3.91 g/100 g dry weight (Schlemmer et al., 2015) and the highest amount of phytate is placed in the aleurone layer of WB (Eeckhout and Paepe, 1999). There was a significant linear relationship (R^2= 0.953) between phytate-P and total P in wheat and wheat co-products and total P, phytate-P, and phytate-P/total P ratio in wheat (0.33, 0.22, 0.67) and WB (1.16%, 0.97%, 0.84) (Eeckhout and Paepe, 1999) (Table 9). Cereal grains have high total phosphorous and 2/3 of the P content in the phytate form. Phytate is resistant to digestive enzymes (amylase, protease, and trypsin). Phytate degradation in plant cells is important and enhances mineral bioaccessibility in different ways, including enzymatic hydrolysis, heating, fermentation, acidification with lemon juice or lactic acid, and soaking (Attia et al., 2012). Phytate degradation (reducing the sum of InsP6 + InsP5 and increasing available phosphorus) by enzymes is dependent on the matrix surrounding phytate (Brejnholt et al., 2011). Two types of phytases are known in wheat: phytase belonging to the HAP(Histidine acid phosphatases) and PAP(Purple acid phosphatase) classes of phosphate were found in plants (Brinch-Pedersen et al., 2014) and PAPhys (PAP phytases), which are more potent phytases than HAPhys (HAP phytases) (Madsen and Brinch-Pedersen, 2019). Guo et al. (2015) reported that WB incubated with distilled water (80 min, 55 °C) caused endogenous phytase activity 4-fold (13 to 53.5 FTU/g) and reduced phytate content by 70% (45.2 13.5 mg/g).

In enzyme kinetic studies, phytase activity (PhytAc) depended on wheat variety, and in the LOK-1 wheat variety, PhytAc was at the maximum level compared with other high PhytAc varieties (DBW-17, HD-2894, and HUW-234) (Kumar and Sushma, 2021). The other research proved that PhytAc in hard-white cultivars (namely Heyne and Betty) (2.54, 3.12) and hard-red wheat (Jagger, OK95571) (0.92, 3.88) bran more than flour (0.71, 0.86) (0.34, 0.41 FTU/g) and glycanases caused increased phytase extraction in both bran (7.62, 7.34) (4.96, 7.17) and flour and these increase in bran fraction higher than flour fractions (Okot-Kotber et al., 2003). PhytAc in wheat (1193), WB (2957), rye (5130), triticale (1688), and barley (582 units/kg) (Eckhout and Paepe, 1994. Cereals and co-products with high endogenous phytase could effectively enhance utilization of phosphorus in poultry and swine and unprocessed WB contains endogenous phytase activity levels at 5.7 FTU/g (Pointillart, 1991).

The benefits of the intrinsic phytase (pro-nutritional enzyme) content of WB for monogastric animals are improved phytate phosphorus, minimizing phytase addition, minimizing the amount of exogenous phosphate requirements, and reducing the negative effects of phytate in monogastric animals. Phytase enzymes are released and produce bioavailable iron, zinc, and phosphorous by phytate hydrolysis (Madsen and Brinch-Pedersen, 2019). It has also been suggested that in un-pelleted/mash rations and when WB levels are 5% or more, WB could be utilized as a phytase source and lower inorganic P requirements (Cavalcanti and Behnke, 2004). Adding 5% fermented WB to broiler diets increased serum phosphorus levels at the age of 21 days (Saedi et al., 2023).Mohammadi et al. (2018) showed that using 2000 IU/kg phytase and 20 g/kg WB in the diet can improve growth indices and phosphorus absorption rate of common carp (Cyprinus carpio) fry. reported that endogenous phytase from inclusion of unprocessed WB(UWB) to low available P ration (0.35%) could improve P utilization in broilers and inclusion of UWB or microbial phytase in diets causes 0.05% additional dietary available P (Cavalcanti and Behnke, 2004). Considering that phosphorus digestibility is partly caused by the endogenous activity of feed ingredients, it can be said that in wheat varieties with high endogenous activity, the amount of ex-

Table 9. Amount of phytate and intrinsic phytase activity in poultry feedstuffs.

Feedstuff	Total P			Phytate P			Phytate P/ total P			Phytase activity		
	%	g/kg	%	g/kg	%	%	%	%	%	U/ kg		FTU/kg
Wheat		2-3.08	0.44	1.6-2.2		0.27	72-80	59.6	61		1193	255-840
Corn	0.21	2.4-2.62	0.39	1.7-2.05	0.19	0.25	72-85.4	57.4	64	<70	15	24-25
Barley		2.6-3.21	0.39	1.69-1.96		0.20	61-67		61		582	130-595
Sorghum			0.30			0.22			73		24	
Rye	0.25[1]				0.18					2300[1]	5130	
Wheat Bran		10.96	1.11	8.36		0.81	76.3		73		2957	1700-3090
Wheat middling		8.45		7.8			92	61.2				2500
Deoiled rice bran			1.77			1.49			84			
Soybean meal	0.60	6.5-6.66	0.88	3.88-4.53		0.56	60-68	47.2	64	<70	8	10-95
Sunflower meal		9.05	0.90	7.48-7.7	0.45	0.45	82.8-85		51			<10
References*	5	4	2,3	4	5	2,3	4	6	2,3	5	3	4

1. Hybrid 2. Tyagi and Verma (1998) 3. Ravindran et al. (1995) 4. Dersjant-Li et al. (2015) 5. Archs Toledo et al. (2020) 6. Tahir et al. (2012)

ogenous phytase required is lower and phosphorus digestibility is higher (Barrier-Guillot et al., 1996).

Endogenous wheat phytase degraded InsP6 + InsP5 at pH 4 and pH 5, and this was not true for WB and recombinant wheat phytase, and only the microbial phytase was able to degrade the pH 3 to 5 and the efficacy of phytase was affected by the phytate matrix (Brejnholt et al., 2011). For the PhytAc survey on enzyme kinetics, optimal pH 5 (significantly increased with acidic pH but decreased in basic pH), optimum temperature (60 °C), and substrate concentration (sodium phytate at 3mM and calcium phytate at 2Mm) (Kumar and Sushma, 2021).

CONCLUSIONS

According to this review, wheat bran has not been considered adequately, and more attention should be paid to the consumption of WB and fermented WB for poultry nutrition. The fermentation of wheat bran fiber by microbes offers a promising approach to enhance the nutritional qualities of this valuable material. Various studies, particularly those focusing on its use in poultry nutrition, have shown that fermented wheat bran fiber brings about significant improvements in nutrient absorption, growth rates, and gut health indicators. Including an adequate amount of dietary fiber in poultry diets has been proven to stimulate the development of the gastrointestinal tract, promote beneficial gut bacteria, strengthen the immune system, and prevent overeating while still supporting poultry growth, and microflora of yellow-feather chickens. Due to the many benefits of WB, and to reduce feeding costs, WB should be included at rates of 4% and 10-12 % in broiler and layer, respectively. In poultry diets, if WB consumption is higher than 5% it is necessary to make corrections in the amount of exogenous phytase and phosphorus supplied practically in mash diets. Also, special attention should be paid to the fatty acids profile, the ratio of tryptophan to lysine, when the amount of WB consumed in diet is higher than normal. However, more extensive research is needed for enhancing sustainability of poultry production to assess the interaction effects of the level of WB consumed, size of WB particles, different sources, and levels of dietary fat, with the type of poultry strain, rearing conditions, or production period. In addition, changes in the feed formulation should be made if fermented WB is used in poultry. Wheat bran increases amylase and trypsin levels in the pancreas and jejunum. Thus, further research is also needed regarding the optimal levels of exogenous enzymes with different levels of WB and their mutual effects on the mRNA expression of digestive enzymes in different poultry strains.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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