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Evaluating the Nutritional Bioefficacy of Xylanase and Cellulase in Poultry Diets Rich in Non-Starch Polysaccharides

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ABSTRACT

The incorporation of agro-industrial by-products into poultry feed offers a sustainable strategy for reducing reliance on conventional grains while diversifying nutritional inputs. However, the high content of non-starch polysaccharides (NSPs), particularly arabinoxylans and cellulose, limits nutrient utilization in monogastric animals due to increased digesta viscosity and structural barriers to nutrient release. Xylanase and cellulase are two widely studied exogenous enzymes that target these polysaccharides, enhancing nutrient accessibility in high-fiber poultry diets. This review aimed to synthesize evidence on the functional roles of xylanase and cellulase in degrading plant cell wall components and improving feed utilization. The present review synthesizes current evidence on the functional mechanisms of xylanase and cellulase in degrading plant cell-wall polysaccharides and enhancing feed utilization, with particular attention to the application of xylanase and cellulase in diets formulated with wheat pollard, rice bran, and other NSP-rich ingredients. Although numerous studies reported improved feed efficiency, digestibility, and growth performance following xylanase and cellulase enzyme supplementation, proximate analyses often indicated minimal or no changes in crude protein, fiber, or fat contents of enzyme-treated diets. The lack of compositional change, hereafter referred to as proximate compositional stability, has received limited attention as a potential indicator of enzymatic bio-efficacy. By integrating biochemical, nutritional, and physiological evidence, the present study highlights the interpretive gap between chemical composition and biological function in feed evaluation. The review further proposes that proximate compositional stability in an enzyme-supplemented diet does not indicate a lack of enzyme activity; rather, it represents a baseline condition confirming enhanced nutrient utilization. Recognizing this distinction is critical to developing function-oriented evaluation frameworks that support the effective use of fibrous by-products in poultry nutrition, aligned with broader goals of sustainable and resource-efficient animal production.

Keywords: Diet, Enzyme, Nutrient digestibility, Poultry nutrition, Proximate analysis

INTRODUCTION

Ensuring food security remains a critical global challenge, particularly in the face of rising demand for efficient production of animal-based products such as meat, eggs, and dairy. Achieving optimal productivity in poultry farming is heavily dependent on the poultry's ability to effectively digest and assimilate nutrients from feed (Velázquez-De Lucio et al., 2021). The poultry sector in many developing nations is burdened by the high and volatile costs of standard feed ingredients, particularly corn and soybean meal (Alagawany and Attia, 2015). Given that feed expenses can account for up to 75% of total livestock production costs (Tubb and Seba, 2021), interest is increasing in more affordable and sustainable alternatives. Agro-industrial by-products such as wheat bran, rice straw, and fruit and vegetable waste have garnered attention due to their wide availability and residual nutritional value, especially when used in combination with feed additives such as exogenous enzymes (Shah et al., 2025).

Although fibrous feed ingredients offer several benefits, their nutritional value is often limited due to the presence of anti-nutritional factors, especially non-starch polysaccharides (NSPs) and structural carbohydrates such as cellulose and lignin (Jha and Mishra, 2021). Non-starch polysaccharides (NSPs) can increase the viscosity of intestinal digesta through their water-binding capacity, thereby hindering nutrient diffusion and absorption and subsequently impairing gastrointestinal function in poultry (Bedford and Schulze, 1998; Selle et al., 2022). Moreover, poultry, as monogastric animals, lack endogenous enzymes capable of degrading complex non-starch polysaccharides in plant cell walls, such as arabinoxylans and cellulose, which limits their ability to efficiently utilize fibrous feed components (Bedford and

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Schulze, 1998; Perim et al., 2024). Because of this limitation, the nutrients trapped within these fibrous components are often not available for absorption and use in the body (Perim et al., 2024; Perera and Ravindran, 2025).

Exogenous enzymes have been introduced as a nutritional strategy in animal diets as one way to address these constraints. For example, adding xylanase can break down arabinoxylans, which makes the intestines less thick and makes nutrients more available (Cruz et al., 2024). Similarly, cellulase helps break down cellulose into glucose, which can increase energy production from fiber-rich feed (Singh and Kim, 2021). When used together, these enzymes target distinct but related parts of the plant cell wall, and they may have complementary actions that improve nutrient release and the overall effectiveness of digestion (Ababor et al., 2023).

Enhancements in feed conversion ratio, body weight gain, and nutrient utilization are only a few of the benefits documented in the literature regarding the effects of xylanase and cellulase supplementation on animal growth performance. However, far fewer studies have evaluated how these enzymes influence the chemical composition and functional behaviour of fiber-rich feed ingredients, despite increasing interest in understanding their mechanistic role (Cowieson et al., 2016). Specifically, the extent to which xylanase and cellulase impact the proximate composition of fiber-rich poultry feeds remains underexplored. Existing proximate analysis may indicate that crude protein, crude fat, crude fiber, and other components remain largely unchanged following enzyme addition. However, the absence of significant changes in proximate nutrient composition following xylanase and cellulase supplementation does not necessarily imply a lack of biological effects arising from enzyme activity; rather, the findings underscore the analytical constraints of proximate methods, which quantify nutrient concentrations but do not evaluate nutrient accessibility, bioavailability, or reductions in anti-nutritional factors, including soluble non-starch polysaccharides, phytate-related complexes, and fiber-associated compounds that impede nutrient utilization.

The present review critically evaluated available scientific evidence on the application of xylanase and cellulase in poultry nutrition, emphasizing effects on proximate composition, functional digestibility, biological responses, and bio-efficacy in diets rich in non-starch polysaccharides to indicate sustainable and cost-effective feeding strategies.

METHODOLOGY

A structured narrative literature review approach was applied to evaluate the nutritional bio-efficacy of xylanase and cellulase in poultry diets rich in non-starch polysaccharides. Literature retrieval was conducted using Scopus and Web of Science, covering publications from 2011 to 2025. The search strategy employed combinations of keywords, including xylanase, cellulase, poultry nutrition, non-starch polysaccharides, enzyme supplementation, digestibility, and production performance. The approach was designed as a structured narrative review rather than a formal systematic review, with the objective of integrating mechanistic, nutritional, and performance-based evidence across heterogeneous experimental designs.

Eligible studies focused on *in vivo* poultry experiments evaluating xylanase, cellulase, or enzyme combinations and reported feed type, enzyme dosage, experimental duration, and at least one outcome related to nutrient digestibility, energy utilization, or production performance. Studies employing multi-enzyme blends without clearly defined enzymatic activities, trials lacking dosage information, and experiments conducted in non-poultry species were excluded. A minimum experimental duration of 21 days was applied to ensure biological relevance. The literature selection process was summarized in a flow diagram, and key characteristics of the included studies were compiled in Table 2.

Data synthesis was performed through qualitative comparison across studies, emphasizing biochemical effects, changes in nutrient digestibility, gut physiological responses, and production-related outcomes. Interpretation focused on identifying consistent trends, mechanistic explanations of enzyme–substrate interactions, and sources of variation across studies, thereby clarifying how mechanistic pathways translate into functional improvements in nutrient utilization and poultry performance under practical feeding conditions.

COMPOSITION AND LIMITATIONS OF FIBROUS FEED INGREDIENTS

Agro-industrial by-products have increasingly been recognized in recent years as economical and accessible substitutes for traditional feed ingredients in poultry diets. By-products, including wheat bran, rice bran, palm kernel cake, and various fruit or vegetable residues, maintain significant nutritional value (Ogbuewu and Mbajiorgu, 2024). Nonetheless, the application of these by-products in monogastric nutrition is limited by their high fiber content, which is predominantly made up of NSPs, lignin, and other structural carbohydrates that are difficult to digest and utilize efficiently in poultry (Ababor et al., 2023).

The complex structural composition of fibrous by-products presents a significant challenge in their application in poultry feed (Akbari et al., 2024). Non-starch polysaccharides, such as arabinoxylans, cellulose, and β-glucans, are major components of plant cell walls. Poultry do not efficiently digest these carbohydrates because they lack the endogenous enzymes required to cleave the β-glycosidic bonds in these molecules (Raza et al., 2019). Wheat bran may contain more than 25% arabinoxylans on a dry matter basis, significantly enhancing the viscosity of intestinal contents (Bautil et al., 2023). Increased digesta viscosity hinders the transport of digestive enzymes and nutrients within the gastrointestinal tract, leading to decreased absorption efficiency and adverse effects on intestinal health (Singh and Kim, 2021). However, discrepancies in reported effects of high-fiber ingredients often arise from differences in arabinoxylan solubility among feed sources, variations in processing methods such as milling or extrusion, and the developmental digestive capacity of poultry, all of which influence the degree to which viscosity affects nutrient utilization (Bautil et al., 2019; Simic et al., 2023).

Poor nutrient utilization in high-fiber feed ingredients is further exacerbated by lignin, a highly resistant phenolic polymer closely associated with cellulose and hemicellulose in plant cell walls. Lignin forms structural barriers that restrict enzymatic access to polysaccharides and limit nutrient digestibility (Ravindran, 2013). The propensity to form cross-links between carbohydrates and proteins results in a rigid structural matrix that hinders the penetration of digestive enzymes, thereby reducing the overall nutritional value of the feed (Röhe and Zentek, 2021). This helps explain why some studies report minimal performance responses when high-lignin ingredients are included in poultry diets, while others demonstrate positive outcomes only after pretreatment interventions that disrupt lignin–carbohydrate complexes (Leite et al., 2024).

Many fibrous feed items, in addition to structural fiber, contain anti-nutritional factors (ANFs) such as phytates, tannins, and protease inhibitors, which can further limit nutrient utilization (Alabi and Adedokun, 2025). Additionally, structural fiber is a component of many fibrous feed ingredients (Tejeda and Kim, 2021). In particular, these anti-nutritional compounds can bind essential minerals, such as calcium, zinc, and iron, inhibit enzyme activity, and decrease the digestibility of proteins, particularly in young poultry with immature digestive systems (Salim et al., 2023). The simultaneous presence of structural fiber and ANFs reduces nutrient accessibility by creating both physical barriers, such as insoluble cell wall matrices, and chemical barriers, including mineral-binding or enzyme-inhibitory compounds (Bedford and Schulze, 1998). These combined effects significantly limit the nutritional value of fibrous feed ingredients unless mitigated through processing techniques (such as fermentation, extrusion, or soaking) or supplementation with targeted exogenous enzymes (Alabi and Adedokun, 2025).

Assessing feed ingredients based solely on proximate components, such as crude protein, crude fiber, crude fat, ash, and nitrogen-free extract, provides information about their chemical makeup but offers no insight into how much of these nutrients can actually be digested or utilized metabolically by poultry (Pesti and Choct, 2023). Two meals with comparable proximate values may have quite different nutritional effects. This constraint has increased interest *in vitro* digestibility testing and enzyme supplementation studies, which better comprehend fibrous feed components' biological impacts (Shurson et al., 2021). The nutritional potential of fibrous materials is typically limited by physical and chemical obstacles (Tejeda and Kim, 2021). Approximate composition alone may overestimate feed value without targeted treatments such as enzyme inclusion, thereby misrepresenting nutrient metabolic availability. To create economically and nutritionally sound poultry diets, these restrictions must be acknowledged.

MECHANISMS OF ACTION OF XYLANASE AND CELLULASE IN POULTRY NUTRITION

Exogenous enzymes boost feed efficiency and nutritional digestibility in monogastric animals, notably poultry, therefore, they have gained popularity in recent decades (Bedford et al., 2024). These benefits are mainly due to enzymes' capacity to break down NSPs, which otherwise act as anti-nutritional factors by entrapping nutrients within complex plant cell wall matrices (Cozannet et al., 2017). Among these enzymes, cellulase and xylanase remain the most widely studied, as they specifically target arabinoxylans and cellulose, which are commonly found in wheat bran, rice husk, corn DDGS, and other agro-industrial by-products (Abena and Simachew, 2024). Supplementing poultry with microbial xylanase and cellulase releases nutrients, reduces digesta viscosity, and promotes nutrient absorption and microbial balance because they lack the enzymes to break down these fibrous compounds (Al-Qahtani et al., 2021; Velázquez-De Lucio et al., 2021). In addition, partial hydrolysis of cellulose by exogenous cellulase generates soluble oligosaccharides that can serve as prebiotic substrates, selectively supporting beneficial microbes such as *Lactobacillus* and *Bifidobacterium* in the gut (Saini et al., 2022). This microbial modulatory effect has been associated with improved intestinal integrity and competitive exclusion of pathogenic bacteria, further contributing to enhanced poultry health and performance (Morgan, 2023).

Mechanism of action of xylanase

Baker et al. (2021) describe that xylanase primarily functions by hydrolyzing β-1,4-xylosidic bonds in the arabinoxylan backbone, fragmenting large NSPs into smaller xylo-oligosaccharides while simultaneously lowering intestinal viscosity. Reduced intestinal viscosity is essential for improving nutrient absorption, as lower digesta viscosity enhances nutrient diffusion and facilitates greater interaction between nutrients and endogenous digestive enzymes, thereby improving digestive efficiency in poultry (Bedford and Schulze, 1998; Morgan et al., 2022). Xylanase reduces digesta viscosity, which increases the accessibility of starch granules and protein bodies encapsulated within the plant cell wall matrix, thus improving the efficiency of enzymatic breakdown and nutrient uptake (Baker et al., 2024). Studies on broiler chickens indicate that the decrease in viscosity correlates with enhanced villus height and increased absorptive surface area in the small intestine (Velázquez-De Lucio et al., 2021; Bedford et al., 2024). Additionally, xylo-oligosaccharides produced through xylanase activity may function as prebiotics by selectively enhancing the proliferation of beneficial gut microorganisms, thereby contributing to intestinal health and immune response (Baker et al., 2021).

Mechanism of action of cellulase

In contrast to xylanase, cellulase specifically targets the β-1,4-glucosidic linkages present in cellulose, which is a rigid and insoluble fiber constituting the structural framework of plant cell walls (Tong et al., 2024). The degradation of cellulose into glucose and oligosaccharides is facilitated by the supplementation of microbial sources of cellulase, as poultry lack the endogenous capacity to produce this enzyme (Sureshkumar et al., 2023; Perim et al., 2024). This enzymatic action not only improves the energy yield from fibrous feed materials but also facilitates the work of other digestive enzymes, including proteases and amylases, by disrupting the structural integrity of the cell wall (Liu et al., 2025). In addition, the release of fermentable sugars through cellulase activity can support microbial fermentation in the lower gut, although care must be taken to avoid excessive fermentation or overproduction of short-chain fatty acids (Ali et al., 2022). Importantly, cellulase also plays a role in reducing feed bulk, which is particularly beneficial in high-fiber diets commonly used in poultry production systems within tropical regions (Rodrigues and Choct, 2018; Singh and Kim, 2021). These outcomes are especially valuable when formulating economic ration that incorporate agro-industrial by-products with elevated fiber levels.

Synergistic activity and combined supplementation

The combined application of xylanase and cellulase represents a synergistic strategy for enhancing feed degradation, as each enzyme acts on different yet complementary components of the plant cell wall (Suchova et al., 2022). This coordinated activity allows for a more thorough breakdown of structural carbohydrates, resulting in greater nutrient release, reduced intestinal viscosity, and modifications to fermentation patterns within the gastrointestinal tract (Han et al., 2023). Combined hydrolysis of hemicellulose and cellulose breaks the structural matrix more efficiently than either enzyme alone, making it especially useful in diets high in cereal bran or fiber by-products (Lin et al., 2025). This enzyme combination also decreases fermentable non-starch polysaccharides in the hindgut, reducing substrates for unwanted bacterial fermentation (Toghyani et al., 2025). Thus, it improves gut health and may avoid gastrointestinal physiological disturbances (Bedford et al., 2024).

Xylanase hydrolyzes arabinoxylans into xylo-oligosaccharides, lowering digesta viscosity and making nutrients in plant cell walls more accessible (Toghyani et al., 2025). Together, these enzymes enhance nutrient digestibility and feed efficiency in monogastric animals (Velázquez-De Lucio et al., 2021; Bedford et al., 2024). Additionally, this section emphasizes the complementary nature of these two enzymatic actions, highlighting the release of glucose and xylo-oligosaccharides as functional outcomes. These degradation products not only contribute to the host's metabolic energy but also support beneficial microbial populations and suppress pathogen proliferation (Baker et al., 2021). However, the efficacy of enzyme supplementation is significantly influenced by multiple factors, including substrate availability, pH, and thermal stability, enzyme retention time in the gastrointestinal tract, and feed processing conditions (Lee et al., 2024). Thermal stability, in particular, is a critical consideration given that many commercial poultry feeds are pelleted at high temperatures (Lee et al., 2024). To address this, enzyme formulations are often subjected to protective technologies such as encapsulation, which allow the enzymes to retain their activity post-processing and ensure their release at the desired site within the gastrointestinal tract (Velázquez-De Lucio et al., 2021). Table 1 summarizes their primary substrates, mechanisms of action, and associated nutritional effects to consolidate the comparative roles of these enzymes. The Table 1 also reinforces the synergistic nature of xylanase and cellulase when used in combination, offering a practical reference for nutritionists formulating enzyme-supplemented diets for broiler and layer poultry.

Table 1. Functional roles of xylanase and cellulase in poultry feed

Enzyme	Primary substrate	Mechanism of action	Nutritional effect	Reference
Xylanase	Arabinoxylans (Ax)	Hydrolyzes β-1,4-xylosidic bonds; reduces viscosity	Improves nutrient absorption; decreases gut viscosity	(Kiarieet al., 2014)
Cellulase	Cellulose (Insoluble fiber)	Breaks β-1,4-glucosidic bonds; releases glucose	Increases energy value; enhances nutrient accessibility	(Cozannet et al., 2017; Perim et al., 2024)
Xylanase + Cellulase	Hemicellulose cellulose	Synergistic breakdown of plant cell wall	Enhanced nutrient release and feed efficiency	(Velázquez-De Lucio et al., 2021; Bedford et al., 2024)

Table 2. The selected studies evaluating xylanase, cellulase, and their combinations in poultry diets

Enzyme	Feed type	Dosage	Poultry type/duration (days)	Main effects observed	Reference
Xylanase	Wheat-based	1000 U/kg	Broiler / 42 days	Decrease viscosity, increase ADG (+8%), increase villus height	(Raza et al., 2019)
Xylanase	Wheat and corn-soybean	3000 U/kg	Broiler / 35 days	Increase the ileal digestibility of energy, decrease intestinal pH	(Hong et al., 2025)
Ligno-Cellolase	Corn-DDGS, rice bran	0.5% and 0.25%	Broiler / 42 days	Increase FA digestibility, Ileal apparent	(Bogusławska-Tryk et al., 2016)
Cellulase	Barley-hull-based diet	400 U/kg	Layer / 28 days	Increase AMEn, increase crude fiber digestibility	(Teymouri et al., 2018)
Xylanase Cellulase	Wheat bran, soy hulls	500 + 300 U/kg	Broiler / 21 days	Increase CP digestibility, increase villus/crypt ratio, decrease cecal pathogens	(Abule and Ohimain, 2016)
Xylanase Phytase	Corn-soy	1000 U/kg	Broiler / 40 days	Increase mineral absorption, increase BWG, decrease cecal VFA	(Gehring et al., 2013)
Xylanase Amylase Protease	Corn-soy	500–750 U/kg (each)	Broiler / 35 days	Increase CP digestibility, increase feed efficiency (FCR decrease)	(Amerah et al., 2017)
Multi-enzyme complex	Rice bran, corn	800 U/kg (blend)	Broiler / 30 days	Increase AMEn, increase fiber degradation, increase microbial balance	(Velázquez-De Lucio et al., 2021)

BWG: Body weight gain; VFA: Volatile fatty acids; AMEn: Nitrogen-corrected apparent metabolizable energy; Corn-DDGS: Corn dried distillers grains with solubles; CP: Crude protein; ADG: Average daily gain; FCR: Feed conversion ratio

ENZYME SUPPLEMENTATION AND FEED DIGESTIBILITY IN POULTRY

The efficacy of enzyme supplementation in poultry nutrition is best reflected not merely through changes in crude chemical composition but through measurable improvements in nutrient digestibility, energy utilization, and overall feed efficiency (Hong et al., 2025). Xylanase and cellulase, the two primary non-starch polysaccharide-degrading enzymes of interest, have consistently demonstrated positive effects in this regard, especially when incorporated into poultry diets containing high levels of fibrous agro-industrial by-products (Velázquez-De Lucio et al., 2021). Xylanase functions by cleaving β-1,4-xylosidic linkages in arabinoxylans, thereby reducing digesta viscosity, a key barrier to efficient nutrient absorption in monogastric animals (Velázquez-De Lucio et al., 2021; Sureshkumar et al., 2023). Cellulase targets β-1,4-glucosidic bonds in cellulose, facilitating the breakdown of plant cell wall structures into smaller oligosaccharides and improving nutrient accessibility in the gastrointestinal tract (Ravindran, 2013). Although poultry do not produce endogenous cellulase, exogenous supplementation facilitates the degradation of cellulose-rich feed components such as wheat bran and rice husk. Together, these enzymes act on structurally complementary substrates, enabling a broader and more effective breakdown of complex plant cell wall polysaccharides (Velázquez-De Lucio et al., 2021; Bedford et al., 2024).

Previous studies, including both experimental and meta-analyses, have consistently demonstrated the positive impact of these enzymes on apparent digestibility coefficients and energy extraction in poultry diets (Raza et al., 2019; Sekh and Karki, 2022; Cruz et al., 2024). For instance, xylanase supplementation in wheat- and rye-based broiler diets has been shown to increase apparent metabolizable energy (AME) by 3%-6%, along with improvements in ileal digestibility of amino acids and dry matter, although the optimal inclusion level varied depending on feed composition and enzyme activity specifications (Raza et al., 2019). The efficacy of cellulase and other carbohydrase enzymes has been demonstrated in commercial broiler strains, including Ross 308 and Cobb 500, where supplementation improves nutrient digestibility and growth performance (Wang et al., 2005; Ravindran, 2013). These synergistic formulations not only optimize the release of encapsulated nutrients but also positively influence gut morphology and microbiota balance, likely through a reduction in fermentable substrate availability for undesirable microbial populations (Abule and Ohimain, 2016). The choice and proportion of enzyme blends, however, must be tailored to the specific fiber profiles of the feed ingredients used, as different substrates require different catalytic specificities and activity ranges. Factors such as pH stability, thermal resistance during feed processing, and retention time in the gastrointestinal tract further influence the *in vivo* activity of these enzymes, making formulation precision a critical determinant of efficacy (Velázquez-De Lucio et al., 2021).

Importantly, these digestibility improvements often occur in the absence of significant changes in the feed's proximate composition (Pesti and Choct, 2023). Crude protein, crude fat, or fiber levels may remain numerically similar between enzyme-supplemented and control diets; however, improvements in poultry performance, including feed conversion ratios, weight gain, and nutrient retention, suggest enhanced functional utilization of nutrients (Bedford and Schulze, 1998). This discrepancy highlights the limitations of conventional proximate analysis as an indicator of feed quality in enzyme-supplemented poultry diets, because it measures only chemical presence but not nutrient accessibility or metabolic use (Pesti and Choct, 2023). The enzymes do not increase the absolute nutrient content but rather improve the biological availability by dismantling structural cell-wall barriers and reducing anti-nutritional constraint that hinder digestion and absorption (Shurson et al., 2021). Therefore, evaluating enzyme efficacy should include digestibility coefficients, energy utilization, gut morphology, and microbial shifts, rather than relying solely on proximate composition values (Bedford et al., 2024). Evidence consistently shows that exogenous carbohydrases improve nutrient utilization in poultry. Xylanase is particularly effective in corn-based diets; supplementation at 2,000-3,000 U/kg can offset 80-100 kcal/kg of dietary energy reduction while maintaining growth performance, digestibility, and gut viscosity (Cruz et al., 2024). Similar benefits in nutrient digestibility and feed efficiency have been reported across wheat–barley and corn systems (Toghyani et al., 2025). For cellulase, evidence is less consistent when used alone. Most positive results come from multi-enzyme blends, where inclusion rates of 50-150 mg/kg improved nutrient and energy utilization in broilers fed high-fiber corn or wheat diets (Sekh and Karki, 2022). Thus, integrating enzyme use with routine digestibility assays and viscosity measurements can guide precise dietary adjustments in commercial settings (Bedford and Schulze, 1998). These recommendations provide a direct framework for poultry producers to optimize feed efficiency when using fiber-rich by-products, ensuring both improved performance and lower feed costs in commercial broiler and layer systems.

PROXIMATE NUTRIENT STABILITY CONFIRMS ENZYMATIC CONTRIBUTION TO FEED EFFICIENCY

In enzyme-supplemented poultry diets, proximate composition analysis plays a crucial role, not to measure enzyme efficacy directly, but to confirm that any observed improvements in animal performance, such as enhanced growth or feed efficiency, are not the result of differences in the base nutrient composition (Lee et al., 2023). Instead, these effects can be attributed to improve the nutrient availability mediated by the enzymatic breakdown of indigestible components such as NSPs (Yuan et al., 2017). Numerous studies have demonstrated that xylanase- and cellulase-based supplementation in standard poultry diets improves nutrient digestibility, AME, growth rate, and feed conversion ratio (FCR) as a result of NSP degradation rather than from any alteration in macronutrient supply (Bedford and Schulze, 1998; Amerah et al., 2017; Velázquez-De Lucio et al., 2021). Across these diets, crude protein, crude fat, crude fiber, ash, and dry matter values consistently remain comparable between enzyme-supplemented and non-supplemented feeds, while enhanced performance is linked to reductions in digesta viscosity and improved nutrient accessibility. Common poultry ingredients such as wheat pollard and rice bran contain substantial arabinoxylans and cellulose, and the inclusion of exogenous carbohydrases facilitates their hydrolysis without modifying proximate nutrient profiles (Cruz et al., 2024; Hong et al., 2025). Accordingly, proximate analysis serves as a confirmatory measure, ensuring that improvements in broiler performance can be attributed to enzyme-driven NSP degradation rather than to changes in dietary nutrient levels, a principle consistently emphasized across enzyme–nutrition (Bedford and Schulze, 1998; Selle et al., 2022). The demonstrated stability of proximate nutrients in enzyme-supplemented poultry diets provides practical value for commercial production, as carbohydrases allow higher inclusion of NSP-rich by-products such as wheat pollard and rice bran while maintaining feed efficiency, reducing formulation costs, and supporting more flexible diet strategies (Bautil et al., 2023; Perera and Ravindran, 2025).

RESEARCH GAPS AND FUTURE DIRECTIONS

Although xylanase and cellulase have been widely applied in poultry nutrition, several critical areas of investigation remain insufficiently explored. One major gap involves the precise interaction between enzyme specificity and substrate variability. While these enzymes are known to act on arabinoxylans and cellulose, the structural diversity of NSPs across feed ingredients such as wheat pollard, rice bran, and soybean meal introduces considerable variability in enzymatic efficacy (Bedford et al., 2024). Current formulations often apply fixed enzyme doses, yet optimal activity likely depends on the NSP content, solubility, and matrix encapsulation level unique to each feed ingredient. Additionally, the physiological consequences of enzyme supplementation beyond nutrient digestibility have not been fully characterized. While improvements in AME and FCR are frequently reported, far fewer studies address the influence of carbohydrase enzymes on gut morphology, mucosal immunity, and microbial ecology (Raza et al., 2019; Bedford et al., 2024). Emerging evidence suggests that NSP hydrolysis products, such as oligosaccharides, may exert prebiotic effects that reshape microbial populations and impact host health, but these effects remain largely unquantified in poultry systems (Abule and Ohimain, 2016). Most published studies still rely on proximate composition and basic growth metrics to infer enzyme efficacy, but these measurements fail to capture the dynamic processes of nutrient release and utilization (Amerah et al., 2017). Therefore, more mechanistically driven studies, employing tools such as ileal digestibility assays, intestinal histomorphometry, and metabolomic profiling to assess how enzymes modulate digestion and physiology *in vivo* (Amerah et al., 2017; Velázquez-De Lucio et al., 2021).

Furthermore, standardization across trials remains a challenge. Variability in enzyme source, activity units, thermal tolerance, and delivery methods (encapsulation versus uncoated) makes it difficult to compare results or define optimal inclusion rates (Lee et al., 2024). Consistent reporting of enzyme characteristics and feed NSP composition would greatly enhance the reproducibility and translational value of future studies. Overall, bridging these gaps will require interdisciplinary collaboration between poultry nutritionists, enzymologists, and gastrointestinal physiologists. Emphasis should be placed on linking molecular and structural data to animal-level performance, thereby translating biochemical actions into applied benefits within diverse production systems.

CONCLUSION

Xylanase and cellulase supplementation represent a biologically precise strategy for improving nutrient utilization in poultry diets containing high levels of non-starch polysaccharides. By targeting structural carbohydrates such as arabinoxylans and cellulose, these enzymes reduce digesta viscosity and disrupt plant cell wall matrices, thereby enhancing nutrient release and absorption. This mechanism is particularly relevant for diets formulated with NSP-rich ingredients such as wheat pollard and rice bran, which are commonly used in cost-effective poultry rations. Proximate analysis of enzyme-supplemented and control diets confirms that key nutrient levels such as crude protein, ether extract, and crude fiber remain statistically comparable. This compositional ability supports the conclusion that observed improvements in performance metrics, including feed conversion and growth rate, are attributable to enzymatic action rather than to differences in nutrient content. These findings reinforce the importance of evaluating feed not only by its chemical composition but also by its functional bioavailability. Enzyme inclusion enables greater use of fibrous by-products while maintaining or enhancing nutritional efficacy. Continued advances in enzyme formulation, application specificity, and functional assessment will be essential to fully realize the potential of carbohydrates as integral tools in sustainable poultry nutrition.

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Authors' contributions

Zulfi Nur Amrina Rosyada contributed to the literature search, data extraction, and drafting of the manuscript. Mirni Lamid supervised the work, provided critical revisions, and finalized the manuscript. Mohammad Anam Al Arif contributed to the conceptualization and synthesis of the reviewed data. Rimayanti assisted in compiling references and organizing thematic sections. Widya Paramita Lokapirnasari contributed to the interpretation and integration of information from multiple sources. Siti Rani Ayuti assisted in preparing tables, figures, and summarizing key findings. Aswin Rafif Khairullah and Zein Ahmad Baihaqi contributed to the critical appraisal of the reviewed studies and manuscript editing. Rakhi Gangil provided scientific input, reviewed the manuscript, and guided the overall structure and content of the review. All authors participated in revising, reviewing, and confirming the final edition of the manuscript.

Competing interests

The authors have not declared any conflict of interest.

Availability of data and materials

All data and materials supporting this review article are available from the corresponding author upon reasonable request.

Ethical considerations

All authors confirm that ethical issues, including plagiarism, consent to publish, research misconduct, data fabrication and/or falsification, double publication and/or redundant submission, have been carefully considered and addressed during the preparation of this review article. Generative artificial intelligence tools were used solely to support language editing, grammar refinement, and improvement of sentence clarity. Specifically, PaperPal was employed to enhance readability and linguistic consistency without generating scientific content, interpreting data, selecting literature, drawing conclusions, or influencing the scientific arguments. All intellectual content, data interpretation, and final necessary revisions remain the full responsibility of the authors.

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