Indian J Anim Health (2024), 63(2): 207-215
DOI: https://doi.org/10.36062/ijah.2024.08423

Review Article

Dietary manipulation through carbohydrase enzyme supplementation for broiler production in India

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Abstract

Maize, wheat and soybean meal are three important ingredients in commercial broiler chicken diets in many parts of the world including India, containing varying levels of different anti-nutritive factors hampering the normal digestion and absorption of nutrients including carbohydrates and proteins in the digestive tract. The increase in demand for raw ingredients and the diversion of feed ingredients towards other sectors increased the cost of feeding in broiler production. Dietary modification is the tool to enhance feed efficiency so that birds have better growth with lesser feed cost. Supplementing carbohydrases to the broiler diet marginally deficient in energy grew better, had a better feed efficiency ratio (FER), improved retention of protein and fat as well as increases the carcass yields by reducing processing losses. Thus, energy level can be reduced marginally in broiler diet than standard with supplementing their diets with carbohydrases without any adverse effect on economic broiler production. This paper reviews the nutritional strategies (carbohydrases supplementation) that can be used in economic commercial broiler production via better growth and better nutrient utilization.

Keywords: Broiler, Energy, Enzyme supplementation, Maize, Multicarbohydrases

Highlights

- We reviewed the present scenario and challenges of the broiler industry in India.
- Beneficial effects of carbohydrases supplementation on the growth pattern of broiler
- Effect of carbohydrases supplementation on nutrient utilization, carcass traits and economics of broiler production

INTRODUCTION

Feed enzymes are most researched feed additive. In animal feed, enzymes are mostly used for poultry and pigs to eliminate the harmfull effects of nonstarch polysaccharides (NSP) present in cereals such as wheat, maize, barley and triticale, etc. It has been suggested that various enzyme activities may be used to improve nutrient utilization in livestock/poultry (Cowieson *et al.*, 2010). Numerous feed enzymes used as feed additives over the past several years in the animal feed sector include cellulase, xylanases, amylase, galactosidases, lipases, phytases, etc. According to Nikam *et al.* (2016), β-glucanases and xylanases help in the digestion of β-glucans and arabinoxylans, respectively, in barley, oats, wheat, rye and triticale, enhancing the nutritive value of the grains. The cocktail of enzymes instead of a single enzyme represents advancements in feed enzymes and may have a synergistic and additive effect on nutrient utilization and livestock performance. Nutrients in raw feed exists as multiple complexes with different linkages to carbohydrates, proteins, fats and fibers.

At present, energy demands of the broiler diets are fulfilled mainly by maize. Commercially, maize contributes up to 70% and 35% of metabolizable energy and protein requirements of broilers, respectively. Shifting of feed ingredients from the feed industry to bio-fuel production and increase in the

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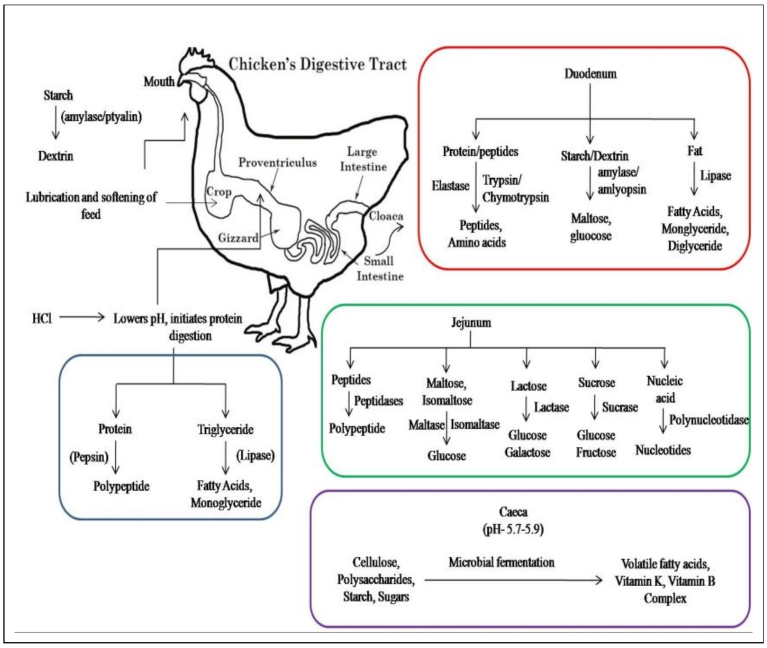

Fig. 1. Schematic presentation of enzymatic digestion in poultry

prices of these raw ingredients open the ways to find out less costly and alternate sources of energy and protein for poultry feed ingredients like barley, triticale, rye, oat, sunflower meal and olive cake (Al-Harthi, 2017; Teymouri *et al*., 2018; Waititu *et al*., 2018), which can be used as substitute of soybean, corn and wheat, but these feed ingredients contain some anti-nutritional factors, adversely affecting intestinal health and growth.

Soybean contains complex carbohydrate called alpha galatosaccharides commonly called as oligosaccharide (stachyose, raffinose, cellobiose) can be upto 12% of the carbohydrate content of the soybean (Leeson and Summers, 2009). Soybean meal contains higher amount of nonstarch polysaccharides than corn and wheat. Meng *et al*. (2005) reported that the total and water-soluble NSP contents of corn were 76.3 and 6.4 mg/g, respectively. Whereas the values for soybean meal were reported to be 136.7 mg/g and 13.4 mg/g, respectively. Cowieson (2010) estimated that around 400-450 kcal of utilizable energy per kg of diet is undigested when birds are fed a typical corn-soy ration.

Endogenous enzymes are not able to digest the non starch polysaccharides encapsulating the nutrients, but their digestion can be achieved by exogenous enzymes. A schematic presentation of endogenous enzymatic digestion of feed is presented in Fig. 1.

A combination of undigested nutrients including undigested fat, undigested protein, and undigested starch contributes to this energy loss, indicating that NSP-induced intestinal viscosity is not a problem in broiler chicken, but NSP compounds have the ability to encapsulate the nutrients; thus, hindering their digestion and absorption. In addition, these complex polysaccharides increase the harmful bacteria in gut microbiome and exogenous enzymes in such a diet increase the number of favorable bacteria in the gut microbiome. Exogenous feed enzymes improve the growth performance, nutrient utilization, and gut health of the broiler chicken (Kiarie *et al*., 2014). Therefore, enzyme supplementation in poultry diet plays a crucial role in increasing the availability of nutrients while reducing the adverse effects of anti-nutritional factors found in the feed (Cowieson *et al*., 2019) as shown in Fig. 2.

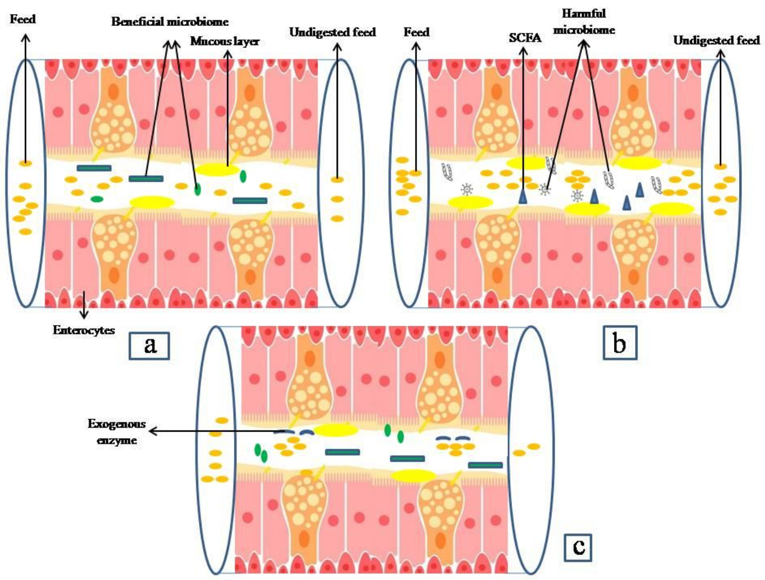

Fig. 2. Effect of exogenous carbohydrases in fibre rich basal diet on digestion of feed and gut microbiome. (a): Standard basal diet (considerable nutrient loss); (b): Diet rich in fibre (more nutrient loss with more number of harmful microbes in gut microbiome; (c): Basal diet rich in fibre + exogenous enzyme supplementation (carbohydrases) (less nutrient loss with more number of beneficial microbes in gut microbiome)

Thus, at present, when the major raw feed ingredients (particularly maize consisting most part of poultry feed and it contributes major part of ME) are becoming costly as being diverted towards other sectors, leading us to discover their alternative or any dietary manipulation to enhance the feed efficiency to alleviate the crisis. This paper reviews the present scenario and challenges of broiler chicken production in India and dietary manipulation through supplementation of exogenous enzymes (carbohydrases) like xylanase, α-amylase, mannanase individually or in combination in poultry diets for efficient utilization of feed via reduction in nutrient loss and make them available to the birds enhancing feed conversion ratio (Gracia *et al.*, 2003; Cowieson, 2010).

Broiler industry: Current scenario and challenges

With the increase in the world's population, particularly in developing countries like India, feeding people a nutritionally balanced diet at an affordable price can be fulfilled by chicken meat as it contains good quality and quantity of protein is the main concern. India is the fifth-largest chicken meat producer. In developing countries, poultry meat consumption increased to 35 million tonnes between the 1990s and 2005, almost double that of developed countries (Narrod *et al.*, 2008). Henderson (2015) found that BRICS countries (Brazil, Russia, India, China and South Africa) contribute 40% of global consumption and play a major role in fueling the growth of protein export from countries like the USA. Among Asian countries, India's poultry sector has had an impressive growth rate in the last few decades. The poultry industry has rapidly grown with an average annual growth rate of 9% from 2000-2001 to 2018-2019 (DAHD, 2020). The increase in domestic demand for chicken meat placed India among the top producers of poultry globally (FAOSTAT, 2018).

On global scale, maize and wheat are the main sources of energy in commercial poultry diets along with soybean as a source of protein and their inclusion rate can be up to 70-75%. Thus, the demand for maize and wheat is also increasing with the rise in poultry production, as they are the major ingredients of poultry feed. Worldwide rise in poultry meat consumption enhances the global maize production to grow at a compound annual growth rate (CAGR) of 5.5% from 729 MMT in 2004-2005 to 1060 MMT in 2015-2016 (shows approximately 69% increase) (FAOSTAT, 2018). In India, meat production has increased from 4.0 million tonnes in 2007-2008 to 7.7 million tonnes in 2017-2018 (nearly double in ten years) with a CAGR of 6.1% and witnessed an annual growth rate as high as 13.25% in 2011-12, a boom in commercial poultry by large integrators (Nanda *et al.*, 2022).

Nowadays, the bulk supply of cereal grains is being diverted towards bio-fuel production. According to NITI Aayog (2021), sugarcane and paddy are using 70% of the country's irrigation water, thus, reducing the water availability for other crops. Therefore, modifications in crop patterns are crucial to reducing dependence on a particular crop and more use of eco-friendly crops for ethanol production (from cereals, particularly maize). The National Policy on Biofuels- 2018, aims an indicative target of 20% ethanol blending under the Ethanol Blended Petrol (EBP) Programme by 2030 (Road Map of Ethanol Blending in India 2020-25, NITI Aayog, Ministry of Petroleum and Natural Gas, GOI, June 2021). Therefore, it is a need for time to discover new nutritional strategies to alleviate the same and to sustain poultry farming in India.

Poultry feed accounts for 47% of the total maize consumption in India (FICCI, 2018). Maize is the preferred energy source in the poultry sector and is expected to rapidly grow from 26 MMT in 2016-2017 to 45 MMT by the year 2022, but India's maize yield which is 2.5 MT/hectare is significantly lower than the global average (5.5 MT/hectare) (FICCI, 2018). The cost of feed in relation to the price of soybean and maize has a serious effect on the competitiveness of the poultry industry, as input costs related to the feed cover 60-70% of the total cost of production. Soybean production declined ($P<0.05$) during 2015-2016 due to unavoidable drought conditions. However, from 2010 to 2015, soybean and maize prices significantly increased at a CAGR of 9.8% and 9.1%, respectively, while the price of chicken increased by only 4.5% (USDA FAS, 2016). Hence, to reduce the feed cost, it is important to improve feed conversion ratio (FCR). Singh (2019) reported that FCR increased by 40% owing to a gain in productivity along with efficient feeding practices. In addition, physical characteristics of the wheat are also very important criteria influencing the broiler performance. With the rise in per capita income in India, meat and poultry consumption has increased, which resulted in a rapid increase in the demand for maize as feed.

An increase in feed costs per unit of production at commercial poultry farms is a major concern for the industry, and the current increase in the price of feedstuffs has generated an interest in exogenous enzyme supplementation in corn-soy-based diets (Cowieson, 2010). Poultry diets consisting of maize-wheat-soy contain varying levels of different anti-nutritive factors (high molecular weight water-soluble nonstarch polysaccharides -NSP), hampers the normal digestion and absorption of nutrients, including carbohydrates and proteins in the digestive tract (Knudsen, 1997). Thus, to meet the demand and supply of poultry meat at economic price can be achieved by better utilization of current feed ingredients or by substituting part of major cereals with other cereals after adding exogenous enzymes (carbohydrases) as feed additives in the poultry feed. Therefore, this article reviews the scope of exogenous carbohydrases supplementation in poultry diet and effect of these enzymes on the performance, nutrient utilization, feed conversion and carcass characteristics for economical production of poultry chicken.

Beneficial effects on growth performance of broiler fed on diets supplemented with exogenous carbohydrase

It is well established that nonstarch polysaccharide (NSP) content of feed and digestibility of nutrients particularly carbohydrate is inversely related. Various feed ingredients used in formulation of poultry diet contain varying levels of anti-nutritive factors and nonstarch polysaccharide. NSP contents of various feed ingredients is shown in Table 1 (Irish and Balnave, 1993). Cowieson and Adeola (2005) found the additive effects of xylanase (X), amylase (A), protease (P), and supplementation in the diet of broiler chicken as a 6 to 7% improvement in body weight gain and 14% improvement in body weight with a combination of phytase and XAP. Thus, supplementation of XAP and phytase individually in a corn/soybean meal-based poultry feed is very effective in improving the performance and nutrient digestibility in broilers. Various exogenous enzymes supplemented in the poultry feed with their target substrate and target feedstuff are as depicted in Table 2 (Ojha *et al*., 2019).

The effect on growth performance of broiler fed on wheat-based feed supplemented with xylanase has not been consistent in different wheat varieties due to the quality of wheat, variation in chemical and/or physical structure of the wheat, xylanase, breed and age of the birds or due to hindgut microflora (Choct *et al*., 2006). Other factors causing variation between individual birds within the same treatment group include water intake patterns, diurnal rhythms, and pancreatic serous secretion output (Bedford and Schulze, 1998).

Gracia *et al.* (2003) found that birds fed with the α-amylase-supplemented diet had higher feed intake, grew faster and had better feed conversion. Further, at 7 days of age, α-amylase supplementation improved

Table 1. NSP contents of some cereals on % DM basis (Irish and Balnave, 1993)

Cereal		Arabinoxylan	β- glucan	Cellulose	Total
Wheat	Soluble	1.8	0.4	2	2.4
	Insoluble	6.3	0.4	-	9.0
Barley	Soluble	0.8	3.6	3.9	4.5
	Insoluble	7.1	0.7	-	12.2
Rye	Soluble	3.4	0.9	1.5	4.6
	Insoluble	5.5	1.1	-	8.6
Triticale	Soluble	1.3	0.2	2.5	1.7
	Insoluble	9.5	1.5	-	14.6
Sorghum	Soluble	0.1	0.1	2.2	0.2
	Insoluble	2.0	0.1	-	4.6
Maize	Soluble	0.1	-	2.0	0.1
	Insoluble	5.1	-	-	8.0
Rice	Soluble	T	0.1	0.3	0.3
	Insoluble	0.2	-	-	0.5
Soybean	Soluble	2.7	-	4.4	2.7
	Insoluble	16.5	-	-	16.5

Table 2. Type of commercial animal feed enzymes and target substrates (Ojha *et al*., 2019)

Enzyme	Target substrate	Target feedstuff
Phytases	Phytic acid	Plant based feed sources
β-Glucanases	β-Glucan	Barley, oats, rye
Xylanases	Arabinoxylans	Wheat, triticale, fibrous plant complexes
α-Galactosidases	Oligosaccharides	Linseed meal, leguminous grain
Proteases	Proteins	Plant derived protein ingredients
Amylase	Starch	Cereal grains, leguminous grain
Lipases	Lipids	Fats in feed sources
Mannanases, cellulases, hemicellulases, pectinases	Cell wall matrix (crude fibre)	Plant-origin fibrous ingredients

the feed conversion by 4.2% and daily weight gain by 9.4%. According to Cowieson *et al.* (2019), supplementation of á-amylase in corn–soybean based diet increases the starch and energy digestibility in broiler chickens. Xylanase efficiently degrades arabinoxylans of the cell wall and releases the encapsulated starch along with other nutrients, at the same time reducing the viscosity of digesta. The overall effects are improvement in the growth performance and nutrient digestibility, better consistency of droppings and modifications in the microflora and micro-fauna of distal gut (Cowieson *et al.*, 2019). Purushothaman *et al.* (2013) concluded that mannanase supplementation improved the dry matter and crude fibre digestibility, and thus, its supplementation supported comparable growth in the low energy diet fed broilers and resulted in low feed cost/kg weight gain in broilers fed on a diet marginally deficient in energy (NE minus 100 Kcal/kg).

The overall performance of broilers chicken fed on diets supplemented with multicarbohydrase (xylanase @ 50 mg/kg + mannanase @ 50 mg/kg + amylase @ 40 mg/kg) had a better feed efficiency ratio (FER), followed by individual xylanase-supplemented broilers. Supplementation of multicarbohydrase to marginally deficient energy diet (ME minus 100 Kcal/kg) improved the growth performance of broilers and retention of protein and fat (Govil *et al.*, 2017b). However, supplementation of mannanase showed no significant effect ($P<0.05$) on the performance of broilers. Supplementation of multicarbohydrase in broiler diets has shown a significant increase in carcass yields by reducing processing losses. Thus, energy level can be reduced in broiler diet by 100 kcal ME/kg than standard while supplementing their diets with multicarbohydrase without any adverse effect on birds for economical broiler production (Govil *et al.*, 2016; Govil *et al.*, 2017a, 2017b).

The higher content of damaged starch in hard wheat makes starch easily hydrolysed by α-amylase due to higher capacity of the damaged starch to absorb water and increased amylolysis (Tester *et al.*, 2004). On the other hand, Wiseman (2006) recorded that soft wheat has better hydration patterns thus, having better digestibility of starch. The effect might be due to the type and degree of grinding, heat treatment and feed form of the diet. It has been further reported that hardness of wheat and the digestibility of starch in pelleted diets are negatively correlated due to larger particulate size reduces the surface area for digestive enzymes (Ball *et al.*, 2013). In support of this theory, Peron *et al.* (2005) reported that fine grinding of hard wheat improves the digestibility of starch in broilers pelleted feed. Moreover, Short *et al.* (2000) reported that the endosperm of hard wheat decreases the amino acid digestibility. It has further been suggested that the interaction between the starch granules and the surrounding protein matrix may obstruct enzyme hydrolysis of starch in hard wheat (Peron *et al.*, 2005). Protease enzyme have the capability to hydrolyse the protein matrix; therefore, supplementation of protease enzyme in broiler diet may have a positive effect on digestibility of starch by enhancing the accessibility of amylolytic enzymes to starch granules in the endosperm by hydrolysing the surrounding protein matrix.

Cowieson *et al.* (2010) found that broiler chickens receiving marginally energy-deficient diets have poor feed conversion ratios, which might be due to the lower energy density. Supplementation of glucanase and xylanase in the diet marginally energy deficient diet improved feed conversion ratio (FCR) and ileal nutrient digestibility. When both enzymes were added simultaneously, a sub-additive effect was observed, and the best performance was achieved with the combination of xylanase (16,000 BXU/kg) and glucanase (30,000 BU/kg). Masey *et al.* (2014) reduced the energy in a broiler diet by 100 Kcal/kg and found that the feed conversion ratio was increased in broilers from 0 to 35d and 0 to 42d. However, FCR was significantly ($P<0.05$) improved by enzyme (xylanase) addition during 0 to 35d and 0 to 42d.

Jeichitra and Srinivasan (2013) supplemented the standard broiler diet with 25, 50 and 100 g of xylanase enzyme/tonne feed. Body weights at 2, 4 and 6 weeks of age were significantly ($P<0.05$) influenced by xylanase enzyme supplementation at all inclusion levels. They concluded that the inclusion level of xylanase at 50 g per ton of feed is effective up to six weeks in producing significantly ($P<0.05$) higher body weight than all other inclusion levels.

Effect of carbohydrases supplementation on nutrient utilization, carcass traits and economics of broiler production

The exogenous supplementation of NSP-degrading enzyme may enhance the access of endogenous enzymes to nutrients (e.g., starch granules), thereby releasing the nutrients from complex molecules of the cell wall. In addition, other studies have reported that the addition of exogenous enzymes to corn-soy feed can increase the digestibility of nutrients like crude protein and amino acids (Rutherfurd *et al.*, 2007). Various studies conducted on supplementation of exogenous carbohydrases supplementation, their substrate, inclusion rates and

Table 3. Carbohydrases, substrate, inclusion rates and their effects fed on various poultry feed ingredients

Enzyme	Substrate	Enzyme inclusion rate	Response	Reference
β-glucanase, xylanase, cellulases	Hull-Less Barley	0.5 g/kg	Supplementation of enzyme cocktail in the finisher diet can decrease the adverse effects of high level of hull-less barley on performance of broiler chickens.	Teymouri *et al*., 2018
Glucanases	Barley	52.5 U/kg of barley	Improve the nutritive value of barley-based diets.	Fernandes *et al*., 2016
Xylanase	Corn-soybean meal	50 -200 U/Kg	Energy utilization and digestibility of crude protein and dry matter increased with xylanase.	Stefanello *et al*., 2016
Xylanase, amylase, protease	Corn/soy/wheat	2,000 U/kg, 200 U/kg 4,000 U/kg	Enzymes with direct-fed microbial improved caloric efficiency by reducing the amount of energy needed to produce one kg of body weight gain.	Flores *et al*., 2016
Xylanase, glucanase, mannanase	Wheat-soybean meal	500 mg/kg diet	Enzyme supplementation increases body weight, decreases digesta viscosity, lowers ileal *C. perfringens* and Lactobacillus colonization.	Sun *et al*., 2015
Glucanase, xylanase	Wheat/corn	2500 U/kg, 250 U/kg	Enzymes stimulate performance in young birds and significantly improve ileal and cecal microbial profile.	Munyaka *et al*., 2016
xylanase	Corn-soy (diet energy was reduced by 100 kcal ME/kg diet)	100 mg/Kg	Xylanase supplementation in low energy diet improved growth, nutrient utilization and carcass characteristics in broilers.	Govil *et al*., 2016
α-amylase	Corn-soy(diet energy was reduced by 100 kcal ME/kg diet)	80 mg/Kg	Amylase supplementation in broilers fed low energy-based diets had improved performance, digestibility of crude protein and ether extract as well as carcass trait of broiler.	Govil *et al*., 2017a
Xylanase, mannanase, α-amylase	Corn- soy (diet energy was reduced by 100 kcal ME/kg diet)	50 mg/kg+ 50 mg/kg+ 40 mg/kg	Boilers fed on diet supplemented with cocktail of enzymes in low energy diet improved the overall performance of broiler chicken.	Govil *et al*., 2017b

response are briefly described in Table 3.

Exogenous supplementation of enzymes in broiler chicken can also influence microbial populations due to the changes imposed on the lumen contents (Kiarie *et al*., 2014; Masey *et al*., 2014). In contrary to this, high nutritional value diets respond at a lower extent to NSP enzyme supplementation. Like, supplementation of xylanases is useful in corn-based feed, although the response is lower than in wheat-based diets due to the higher level of NSP in wheat compared to corn (Choct *et al*., 2006; Kiarie *et al*., 2014). According to Bedford and Schulze (1998), xylanases could be efficient in producing xylo-oligomers which acts as a prebiotic, enhancing cecal fermentation in pigs and poultry. The result of this is the secretion of various gut hormones, such as peptide YY, which elicits an ileal brake effect whereby gastric retention and motility are increased.

Supplementation of xylanase increases the digestibility of hemicellulose and energy in broiler fed corn-based diets (Jeichitra and Srinivasan, 2013). Likewise, Gracia *et al.* (2003) reported that α-amylase supplementation of a corn-soy diet may improve nutrient digestibility and growth performance of broilers. Similarly, Purushothaman *et al.* (2013) in his experiment concluded that mannanase supplementation of a corn-soy diet supported comparable growth in low energy feed and resulted in low feed cost/kg weight gain in broilers.

Similarly, Zanella *et al.* (1999) observed improved overall digestibility of crude protein (CP) by 2.9%, which was not equal for all amino acids in broiler chicken fed corn-soy based diet supplemented with commercial enzyme cocktail containing xylanase, protease and amylase. Cowieson *et al.* (2010) found a significant improvement in FCR with no effect on feed intake and a substantial increase in body weight gain by supplementation of xylanase and glucanase in maize-soy-based diets for broilers. This was accompanied by a significant improvement in ileal digestible energy at 42d, supporting the mechanism of increased feed use efficiency. The exogenous multicarbohydrase (xylanase @ 50 mg/kg + mannanase @ 50 mg/kg + amylase @ 40mg/kg) supplementation had improved the overall performance of broilers along with the digestibility of CP fed on a diet marginally deficient in energy (Govil *et al*., 2016; Govil *et al*., 2017a, 2017b).

Cafe *et al.* (2002) fed a nutritionally adequate diet supplemented with a cocktail of xylanase, protease, and amylase to the broiler chicken and found no consistent effect on dressing percentage or yield of breast, thigh, or wing components. Abdominal fat, which is expressed as a percentage (%) of the carcass, was significantly consistently increased by multi-enzyme supplementation at 42 and 49d.

Bharathidhasan *et al.* (2009) found a marginal increase in dressing percentage and carcass yield in enzyme-supplemented groups, although the giblet percentage and weight of organs remained unaffected by the enzyme supplementation; by the same time, there was a numerical decrease in the weights of proventriculus, liver and pancreas. Hajati *et al.* (2009) studied effect of a multi-enzyme @ 500 mg/kg DM (cellulase, hemicellulase, protease, alpha-amylase and alpha-galactosidase) supplementation on carcass characteristics of Cobb 500 broilers, fed on standard corn-soybeanmeal-wheat diets and found significantly ($P<0.05$) improved carcass and thigh percentage at 44d of age.

Cowieson and Adeola (2005) found the additive effect of amylase, protease, xylanase, and phytase in broiler chickens fed on a diet nutritionally marginal in Ca, P and metabolizable energy. The negative control (NC) diet was supplemented with multicarbohydrases such as xylanase, amylase, XAP, and phytase at 100 mg or 200 mg of each enzyme/kg. The combination of phytase and XAP is found highly effective in improving the growth performance of broilers, allowing the formulation of low-cost feed to contribute further to the profitability of poultry farming.

According to Wang *et al.* (2005), during the growing phase in broilers, the exogenous enzyme (xylanase and β-glucanase) supplementation may improve the performance of broilers fed a wheat-based diet. Optimum supplementation of enzymes was reported to be 200 mg/kg. Bharathidhasan *et al.* (2009) fed a diet supplemented with feed enzyme (cellulase- 146 IU/g, xylanase- 241 IU/g, pectinase- 98 IU/g, protease- 74 IU/g, amylase- 778 IU/g, phytase- 33 IU/g) level at 0, 250, 500, 750 and 1000 g/ton of feed to the broiler chicken with a proportionate reduction in metabolizable energy (ME 1.25, 2.5, 3.75 and 5%, less), crude protein (CP 0.75, 1.5, 2.25 and 3%, less), methionine + cystine (0.5, 1, 1.5 and 2%) and available phosphorus (AP 2.2, 4.4, 6.6 and 8.8%, less) and found marginal increase in dressing percentage and carcass yield in enzyme supplemented groups. The giblet percentage and weight of organs among the treatment groups did not differ significantly ($P<0.05$). However, there was a numerical decrease in the weights of proventriculus, liver and pancreas.

Conclusion

Various studies indicated that supplementation of either individual carbohydrase or multicarbohydrases in broiler diet improved the body weight gain, feed efficiency (due to better utilization of nutrients) and increase the carcass yield (by reducing processing losses) of broilers. Thus, supplementation of carbohydrases in marginally deficient energy diet can be done without any adverse effect on broiler performance for economic broiler production.

Conflict of interest: Authors have no conflicts of interest in this study.

Authors contribution: KG, AG, JR: Contributed equally and responsible for drafting of the manuscript; BCD, AO, AKN: Responsible for literature search and preparation of rough draft; SKP: Responsible for drafting the manuscript, revision and approval of the final manuscript.

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Received- 21.10.2023, Accepted- 25.08.2024, Published-03.10.2024(Online), 01.12.2024 (Print)
Section Editor: Dr. A. K. Patra, Associate Editor