Effect of enzymes by substitution of corn with wheat on growth performance and digestibility of broilers

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Abstract

Substitution of corn with wheat associated with its variable energy content and detrimental effect on broiler performance. In a case of high-cost yellow corn, several feed producers are choosing to replace yellow corn with other ingredients like wheat, barley or sorghum. The predominant Non Starch Polysaccharides (NSP) in wheat are the pentosans (arabinixylans). Nonstarch polysaccharides create a viscous environment in the gastrointestinal tract of broiler chickens thereby interfering with the digestion and absorption of nutrients. Broilers lack endogenous enzymes to degrade arbino-xylans of wheat. Supplementation of exogenous feed grade enzymes to the cereal based diets improve the performance of broilers. Enzyme supplementation of chicken cereals based diets has resulted in improved starch and nitrogen digestibility as well as improved absorption of starch, amino acids and lipids. Supplemental enzymes such as β-glucanase, xylanase, protease and amylase break the polymeric chains of NSP into smaller pieces, thereby improving their nutritional value. The study concluded that the supplementation of NSP-degrading enzymes in wheat-based diet improve growth performance, ileal viscosity and gastric passage rate in broiler chickens.

Keywords: Corn substitution, Enzyme, Growth, Digestibility, Broilers.

Resumo

Substituição do milho por trigo associada ao seu conteúdo energético variável e efeito prejudicial no desempenho de frangos de corte. No caso do milho amarelo de alto custo, vários produtores de ração estão optando por substituir o milho amarelo por outros ingredientes como trigo, cevada ou sorgo. Os polissacarídeos não amiláceos (NSP) predominantes no trigo são os pentosanos (arabinixilanos). Polissacarídeos sem amido criam um ambiente viscoso no trato gastrointestinal de frangos de corte, interferindo assim na digestão e absorção de nutrientes. Os frangos de corte carecem de enzimas endógenas para degradar arbino-xilanos do trigo. A suplementação de enzimas exógenas de grau alimentar às dietas à base de cereais melhora o desempenho de frangos de corte. A suplementação enzimática de dietas à base de cereais de frango resultou em melhor digestibilidade de amido e nitrogênio, bem como melhor absorção de amido, aminoácidos e lipídios. Enzimas suplementares como β-glucanase, xilanase, protease e amilase quebram as cadeias poliméricas de NSP em pedaços menores, melhorando assim seu valor nutricional. O estudo concluiu que a suplementação de enzimas degradantes de NSP na dieta à base de trigo melhora o desempenho de crescimento, viscosidade e taxa de passagem gástrica em frangos de corte.

Palavras-chave: Substituição de milho, Enzima, Crescimento, Digestibilidade, Frangos de corte.

Resumen

Sustitución de maíz por trigo asociado con su contenido de energía variable y efecto perjudicial sobre el rendimiento de los pollos de engorde. En el caso del maíz amarillo de alto costo, varios productores de alimentos están eligiendo reemplazar el maíz amarillo con otros ingredientes como trigo, cebada o sorgo. Los polisacáridos no amiláceos (NSP) predominantes en el trigo son los pentosanos (arabinixilanos). Los polisacáridos sin almidón crean un ambiente viscoso en el tracto gastrointestinal de los pollos de engorde, lo que interfiere con la digestión y absorción de nutrientes. Los pollos de engorde carecen de enzimas endógenas para degradar los arbino-xilanos del trigo. La suplementación de enzimas exógenas de calidad alimentaria en las dietas basadas en cereales

mejora el rendimiento de los pollos de engorde. La suplementación con enzimas de las dietas basadas en cereales para pollos ha dado como resultado una mejor digestibilidad del almidón y el nitrógeno, así como una mejor absorción de almidón, aminoácidos y lípidos. Las enzimas suplementarias como la β-glucanasa, la xilanasa, la proteasa y la amilasa rompen las cadenas poliméricas de NSP en pedazos más pequeños, mejorando así su valor nutricional. El estudio concluyó que la suplementación de enzimas degradadoras de NSP en una dieta basada en trigo mejora el rendimiento del crecimiento, la viscosidad ileal y la tasa de paso gástrico en pollos de engorde.

Palabras clave: Sustitución de maíz, Enzima, Crecimiento, Digestibilidad, Pollos de engorde.

1. Introduction

The poultry industry is recognized as the most popular emerging industry in the world (Al-Dawood, 2016). Poultry meat is an essential source of dietary protein and the industry has developed high grade poultry because of improved farming techniques, automation equipment, and comprehensive and balanced feeding, and other new technologies (Perini *et al*., 2021). Chicken meat represents a good and cheap protein source compared to red meat. In addition, short productive lifespan, dietary restriction absence and worldwide distribution are all favored the use of poultry products as a major source of animal protein (Husna *et al*., 2017). Total meat production comprises of 4.95 million tonnes, out of which 36.50% of poultry share (PES, 2021).

Corn and wheat are dominant energy sources used in poultry diets worldwide because of their high energy content (Gatrell *et al*., 2014). Maize is the most important inputs in feed mixtures for broilers and uses extensively as an energy source for poultry but its content in diets should be reduced for economic reasons (Zarghi and Golian, 2009). Wheat has long been used as a major feedstuff for monogastric animals. Wheat contains 71% carbohydrates, 13% crude protein and 1.5% fat (Feedipedia, 2013).

Non starch polysaccharides

Most of carbohydrates in wheat contains non-starch polysaccharides (NSPs), derived from cell wall (Mirzaie *et al*., 2012). Although feeds that contain high non-starch polysaccharides (NSP) are relatively inexpensive, these products are often not used in broiler feed due to their poor utilization of nutrients and low feed efficiency. It is well known that supplemental enzymes such as β-glucanase, xylanase, protease and amylase break these polymeric chains into smaller pieces, thereby improving their nutritional value (Cowieson and Ravindran, 2008).

Adding Non-Starch Polysaccharides (NSP) degrading enzymes in poultry diets has increased considerably in recent years. However, the effects of exogenous enzymes can be variable and are dependent on a large number of factors such as the age of the bird and the quality and type of diet (Acamovic, 2001). The use of NSP-degrading enzymes as dietary supplements, may positively affect poultry health and productivity fed diets containing grains such as wheat, rye, barley and oats (Basmacioglu *et al*., 2010). Broilers lack endogenous enzymes required for NSP digestion and thus exhibit a reduced feed efficiency when fiber content is increased even in a nutritionally complete diet (Singh *et al*., 2017) (Table 1).

Table 1. Cereal content of total and soluble NSP (% of dry matter) and water extract viscosity**.**

Cereal	Henry (1985)	Boros and Fras (2015)	Water extract viscosity
		harvest year 2010	Boros and Fras (2015)
			Jurgens *et al*. (2012
	Arabinoxylans 6.6	Winter varieties	2.0*
	β-glucans 1.2	Total NSP 8.6	
Wheat		Soluble NSP 1.4	
		Spring varieties	1.9*
		Total NSP 9.20 Soluble NSP 1.70	
Maize		Soluble NSP 4.7	
		Total NSP 4.3	

*(as % of total NSP)

While protein contents are in form of gluten (Shewry and Halford, 2002). However, wheat contains non-starch polysaccharides, including xylan, glucan, cellulose and mannan that reduce feed efficiency and nutrient digestibility. Of these, xylan makes up dominant proportions averaging 5.4% to 8.0% in Australian wheat, 5.5% to 6.5% in North American wheat and 6.6% to 8.2% in Chinese wheat (Li *et al*., 2002). Xylan is most abundant polysaccharide in plant cell walls in nature, is considered to be primarily responsible for anti-nutritional effects of wheat. Mammals cannot digest xylan because they lack endogenous xylanase.

Xylanase can degrade xylan by randomly hydrolyzing the β-1,4-glycosidic bonds producing different length of xylo-oligosaccharides. Thus supplementation of xylanase in feed has been widely applied for chicks and pigs to promote growth performance. Xylanase, as other non-starch polysaccharide (NSP) degrading enzymes, has several actions: partial hydrolysis of non-starch polysaccharides, decreasing the viscosity of digesta and rupturing plant cell walls to release cellular nutrients for digestion (Meng *et al*., 2005). Supplementation of xylanase in wheat based diets produce more short chain oligosaccharides act as substrates for gastrointestinal ecology (Pluske *et al*., 2002) (Figure 1).

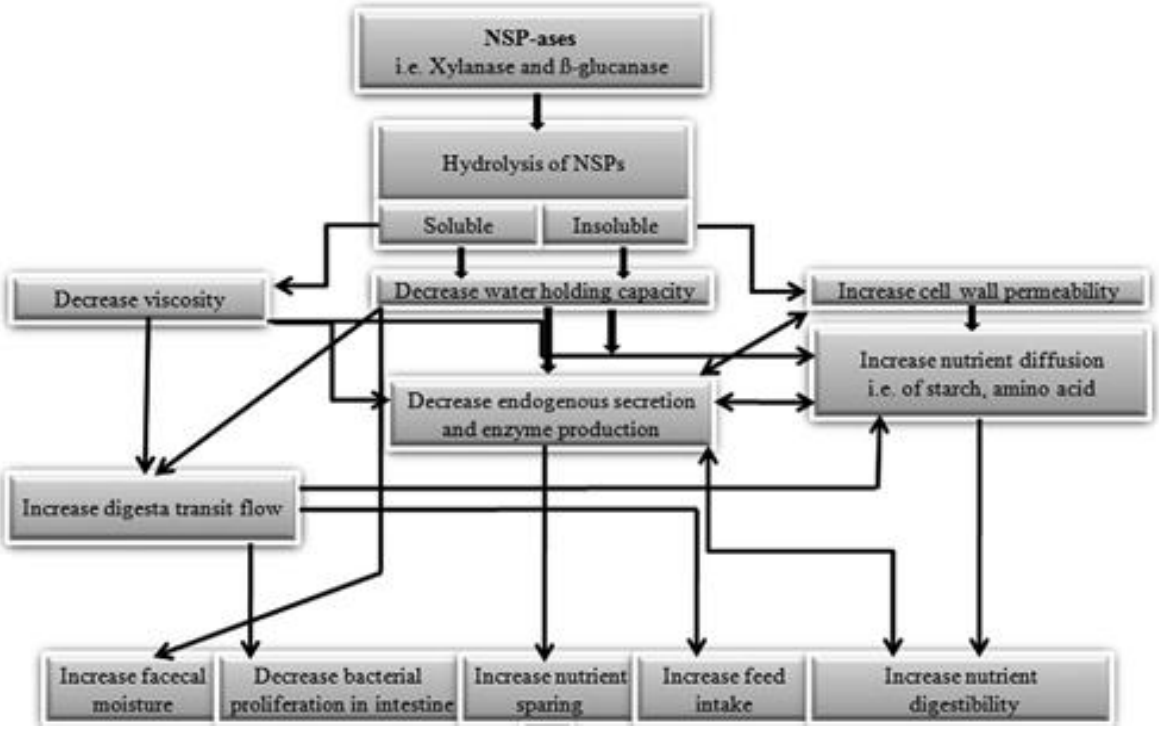

Figure 1. Modes of action of non-starch polysaccharide degrading enzymes**.** Source: (Wyatt *et al*., 2008)

Protein in the form of gluten is not available for mono-gastric animals (Wang et al., 2005). For this purpose, proteolytic enzymes \are used to modify the protein structure of gluten (Adler Nissen, 1986). Various studies have reported that protease supplementation optimizes the nutritional value of feed ingredients, improves protein digestion and growth performance of broilers (Erdaw et al., 2016). The use of exogenous enzyme (protease) can improve the solubility of gluten protein (Kong et al. (2007) by changing its structure at peptide level and produces small size polypeptides which are easy to be absorbed through intestine without any digestion in stomach (Gonzalez-Tello et al., 1994) (Table 2).

Table 2. The maximum recommended dose of individual cereals in the diet of broiler chickens.

Cereal	Addition of feed enzymes	Recommended maximal level in the diet	References
Wheat	–	0–4 wk (young) 20% 4–18 wk (slaughter) 40% 4–20 wk (laying hen) 40% laying hen – without limits	Smulikowska and Rutkowski (2005)
Wheat	+	0–4 wk (young) 40% 4–18 wk (slaughter) 4–20 wk (laying hen) laying hen – without limits	Smulikowska and Rutkowski (2005)

Impact on Growth Performance:

The supplementation of xylanase improves body weight gain and FCR (Yang *et al.*, 2008). The effect of supplementing an enzyme complex to a stored wheat-based control diet showed that up to day 41, and similar for both sexes, live weight was significantly improved by 2.3% respectively (Hadorn *et al*., 2001). In comparison to the females, male broilers had increased body weight (+16.3%). Improved growth performance can be expected for male and female broilers with supplementation of the tested enzyme complex to wheat-based diets. Xylanase inclusion in wheat-based diet improves digestibility and growth performance of broilers (Kalmendal and Tauson, 2012). The supplementation of xylanase in wheat-based diets of broiler showed beneficial effects on growth performance, digestibility of nutrients, intestinal morphology, and micro flora balance (Liu and Kim, 2017).

The effect of partial replacement of corn with wheat grain without or with different commercial enzyme products supplementation on growth performance of broiler chicken showed that wheat inclusion at 25% instead of corn non significantly reduced body weight and gain of broiler chicken, while 50% replacement improved both parameters when compared with chick group fed on corn soybean based diet (Mohamed *et al*., 2014).

In the growing period, broilers attained the highest ($P<0.05$) body weight gain, feed intake, and relative small intestine weight when wheat was substituted at 25% for corn. Xylanase inclusion significantly improved the body weight gain, fat availability ($P<0.01$) and diet metabolisable energy ($P<0.1$) (Chiang *et al*., 2005).

Wheat diets resulted ($P < 0.01$) in better performance than corn diets, whereas xylanase-fed birds had improved ($P < 0.01$) BW gain (2,457 vs. 2,275 g) and feed per gain (1.677 vs. 1.762) relative to birds not fed xylanase (Kiarie *et al*., 2014). The effects of a xylanase and β-glucanase **(XB)** blend (2,500 U of xylanase and 250 U of β-glucanase per kg of complete feed) on growth performance, nutrients utilization and digesta microbiota in broiler chickens were investigated. Birds fed wheat diets had higher (**P**<0.001) BWG (3.4%) than birds fed corn-based diet whilst birds fed XB had better BWG (4%) and FCR (7%) than birds fed non-XB diets (Munyaka *et al*., 2016).

The effects of dietary enzyme supplementation (primarily xylanase and beta-glucanase) on performance of broiler chickens fed wheat-based diets with 0, 200, 400, 600, 800, or 1,000 mg/kg enzyme supplementation improved performance of the broilers; daily gain and feed conversion increased linearly ($P<0.01$) with increasing levels of enzyme supplementation (Wang *et al*., 2005). In a study, the effect of cereal type and sex on broiler performance was examined. Birds in the group fed diets based on wheat as cereal type (males) showed highest values in body weight and body weight gain during overall experimental periods as compared with other groups (Yousif *et al*., 2021).

The birds that were supplemented with corn based diets had improved FCR 1.380 as compared to birds supplemented with sorghum based diet showed reduced FCR of 1.478 (Moss *et al.*, 2020). Broiler weight gains, feed efficiency and apparent metabolizable energy (AME) gets improved with the inclusion of phytase (500 FTU/kg) and xylanase (4400 EXU/kg). Generally, phytase and xylanase improved weight gain and feed efficiency of broiler, so they reported that combined inclusion of phytase and xylanase were more beneficial as compared to individual inclusion (Selle *et al.*, 2003).

The xylanase enzyme reduced the intestinal viscosity and increased the AME of wheat and starch digestibility in jejunum and ileum (Choct *et al.*, 1999). Broiler fed a combination of xylanase and de-branched enzymes showed better gut health and growth performance (Lei *et al.*, 2016).

The abdominal fat pad of the birds which were fed with diets containing 330 g/kg whole wheat was increased by 5.3% (from 18.9 to 19.9 g/kg body weight), compared to those which were fed with diets including ground wheat (Preston *et al.*, 2000). The inclusion of whole wheat increased relative weight of the abdominal fat pad (from 22.1 to 26.4 g/ kg body weight) in birds which were fed with corn–wheat-based diets (Nahas and Lefrancois, 2001).

The supplementation of both super-dosing phytase and xylanase improved carcass yield and breast weight and tended to increase carcass weight while xylanase improved carcass weight and tended to increase carcass yield (Santos *et al*., 2017). The effect of corn replacement with five levels of wheat screening (0, 150, 300, 450 and 600 g/kg of diet) with (0.5 g/kg of diet) or without xylanase and glucanase enzyme on performance of finisher broilers (25-42 days of age). There was not significant differences in feed intake of birds fed with different levels of wheat screening (WS) (Mazhari *et al*., 2015). The birds which were fed whole wheat had lowest weight gain and less FI similarly, birds which were fed ground wheat had high Bifidobacterium population as compared to the bird fed whole wheat (Singh *et al.*, 2019) (Table 3).

Table 3. Effect of corn and wheat along with enzyme supplementation on growth performance.

Cereal	Addition of feed enzymes	Recommended maximal level in the diet	Growth Performance			References
			Feed Intake (g)	Body Weight (g)	FCR	
Corn	Xylanase		3745	2162	1.78	Kiarie *et al.* (2014)
Wheat			4145	2571	1.65	
Corn			4280	2251	1.90	Yaghobfar and Kalantar (2017)
Wheat			4164	2015	2.06	
Wheat+Enzyme			4253	2119	2.01	
Wheat (10 day old bird)		0%	21.53	16.24	1.33	Mazhari *et al.* (2011)
		5%	21.31	15.94	1.37	
		12%	21.74	15.97	1.38	
		18%	21.69	15.03	1.40	
		24%	22.01	13.81	1.50	
Corn	Xylanase			2338		Razuki *et al.* (2017)
Wheat				2362		
Wheat	No Xylanase		1,393	872	1.59	Liu and Kim (2017)
	Xylanase (5625 IU/Kg)		1380	880	1.57	

The effect of four wheat cultivars and 2 levels (0 or 1 kg/t of feed) of an enzyme cocktail (Avizyme 1300, xylanase, 2,500 U/kg and protease, 800 U/kg) on broiler strongly influenced animal performance during the starter period (1 to 21 d of age) (Del Alamo et al., 2008). In a study, the effects of exogenous xylanase supplementation on performance and the degradation of non-starch polysaccharides (NSP) in different sections of the gastrointestinal tract (GIT) of broilers fed wheat-based diets. The results showed that xylanase supplementation improved feed conversion ratio by 5.0% ($P<0.05$) (Zhang et al., 2014). In the growing period, broilers attained the highest ($P<0.05$) body weight gain when wheat was substituted at 25% for corn (Chiang et al., 2005).

Impact on Nutrient Digestibility

Modulation in digesta viscosity

The solubility and molecular weight of NSPs determine the viscosity. The solubility is not specific to the sugar composition or linkage present in NSPs but depends on the chemical structure and association of NSPs with the cell wall components. However, the physical effect of viscosity on digestion and absorption of nutrients appear to be similar regardless of the sources of NSPs. Moreover, the binding of NSPs with the intestinal brush border increases the thickness of the unstirred water layer adjacent to the mucosa, leading to impaired nutrient digestion and absorption (De Lange, 2000) (Table 4).

Table 4. Factors responsible for anti-nutritive effects of non-starch polysaccharides.

Factors	Effects	References
Changes in digesta viscosity	Reduced mixing of digestive enzymes and substrates	
	Hindered effective interaction of digestive enzyme at the intestinal mucosal surface Increased residence time of the digesta Increased intestinal volatile fatty acid (VFA) production	Hossain *et al*. (2001) Leenhouwers *et al*. (2007a, 2007b)
	Impaired nutrient digestion and absorption	
Alteration in the gastric emptying and rate of passage	Reduced rate of gastric emptying	Bach Knudsen (2001)
	Increased rate of passage of stomach content Delayed intestinal absorption of glucose	Hossain *et al*. (2001) Leenhouwers *et al*. (2007a, 2007b)
Alteration of gut physiology	Hinder endogenous secretion of water, proteins, electrolytes and lipids	Hossain *et al*. (2001)
	Enhanced bile acid secretion, and significant loss of these acids in the faeces	
	Hampered absorption of lipids and cholesterol in intestine	
	Limited intestinal enzyme activity	
Alteration in the gut morphology	Increased size and length of digestive organs Reduced concentrations of DNA in jejunum, ileum, and liver, indicating programmed cell death	McDonald (2001) Iji *et al*. (2001); Leenhouwers *et al*. (2006)
	Augmented concentrations of RNA in the colon	
	Reduced villi length	
	Increased depth of intestinal crypts in jejunum and ileum	
	Impaired water absorption, can lead to dehydration	
	Increased rate of turnover of intestinal mucosal cells	
Alteration in the native gut microflora	Stimulated microbial fermentation in intestine.	Amirkolaie *et al*. (2006); Leenhouwers *et al*. (2007a, 2007b)
	Enhanced volatile fatty acids, such as acetic acid, propionic and butyric acids, production Lower pH of intestinal tract; in long term may disturb the normal micrbiota prevailing in gut	
	Influenced bioavailability of dietary minerals Decreased oxygen tension, favouring development of anaerobic microbiota	

The xylanase (6225 U/g) supplementation along with wheat-based diet showed higher apparent digestibility of CP in 21 days and 42 days of age in broilers (Wang et al., 2005). The inclusion of phytase and xylanase in wheat-based broiler diets increases iliac protein digestibility (Selle et al., 2003). With the inclusion of xylanase in wheat-based diet of broiler diet, birds show superior growth performance and nutrient digestibility (Kiarie et al., 2014). A combination of xylanase, amylase, and protease (XAP) can increase the nutrient digestibility of feed (Romero et al., 2013).

The effects of a xylanase and β-glucanase (XB) blend (2,500 U of xylanase and 250 U of β-glucanase per kg of complete feed) on, nutrients utilization and digesta microbiota in broiler had higher (3.5%) starch digestibility than birds fed this diet without XB (Munyaka et al., 2016). The dietary xylanase supplementation in broilers wheat-based diets on functional digestive parameters including ileal digesta viscosity, apparent ileal digestibility had beneficial effects on apparent ileal digestibility of nutrients, intestinal morphology and microflora balance

(Liu and Kim, 2017).

The effects of whole wheat, oats and barley at different inclusion levels on starch digestibility, duodenal particle size distribution for broiler chickens was examined. Starch digestibility was improved ($P < 0.05$) by replacing ground wheat or barley with whole wheat or barley. Romero et al. (2014) reported that xylanase, amylase and protease (XAP) inclusion can improve apparent ileal digestibility (AID) of energy and protein in broiler diets. The addition of xylanase and amylase and XAP both improved AID of fat at d 42 of age compared to the control (Hetland et al., 2002).

The low ileal starch digestibilities when broiler chickens were fed on wheat-based diets increased significantly from 0.79 to 0.95, 0.93 and 0.91, respectively (Svihus and Hetland, 2001). The effects of exogenous xylanase supplementation on nutrient digestibility and the degradation of non-starch polysaccharides (NSP) in different sections of the gastrointestinal tract (GIT) of broilers fed wheat-based diets. Xylanase significantly increased ($P<0.05$) ileal digestibilities of crude protein (CP) by 3.5%, starch by 9.3%, soluble NSP by 43.9% and insoluble NSP by 42.2% relative to the control group, respectively (Zhang et al., 2014). The addition of one or two recommended levels of the different commercial enzymes significantly increased ($P< 0.05$) AMEn and apparent digestibility of fat, protein, dry matter, and organic matter in wheat. However, there was not a significant difference between the levels of added commercial enzymes for improvement in the AMEn and nutrient digestibility (Jamili et al., 2016). The xylanase enzyme reduced the intestinal viscosity and increased the AME of wheat and starch digestibility in jejunum and ileum (Choct et al., 1999). Maize, wheat and sorghum as the main feed grain in standard phytase and xylanase supplemented diets for broiler chickens generated the greatest starch digestibility coefficient in the jejunum and ileum in both starter and finisher diets. In the ileum, broiler chickens offered finisher diets based on wheat B had the highest protein digestibility (Moss et al., 2020) (Table 5).

Table 5. Effects of enzyme inclusion on apparent crude protein digestibility (ACPD) on d 20 to 21 and d 41 to 42.

	Dietary enzyme levels, mg/kg								
	0	**200**	**400**	**600**	**800**	**1,000**	**SEM**	**Linear**	**Quadratic**
Day 20-21 ACPD, %	60.89	61.68	62.32	63.33	62.3	63.82	0.561	<0.01	0.56
Day 41-42 ACPD, %	61.51	62.77	63.33	63.92	63.17	64.98	1.115	0.05	0.81

Source: (Wang *et al*., 2005)

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