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Feed Fermentation in Poultry Nutrition

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Fermentation has been used recently in poultry nutrition due to having great potential. It can improve the nutritional composition of feedstuffs, eliminate antinutritional components, enrich with enzymes, phenolic compounds and coloring agents. Fermented feedstuffs can increase performance, feed utilization, digestibility, immunity, antioxidant capacity, intestinal microflora in poultry. Improvements of feedstuffs by fermentation and effects of fermented feedstuffs on poultry are summarized in this study.

Introduction

Fermentation has been carried out traditionally for many years. It has received great interest from researchers for detoxification and biotransformation of agricultural residues. Fermentation may be divided into liquid-state and solid-state fermentation. Solid-state fermentation is preferred to liquid state fermentation in bioconversion of agricultural residues because of the being economical and having relatively less risk of contamination (Pérez-Guerra et al., 2003). Solid state fermentation (SSF) is defined as a microorganism activity on moist solid substance in absence of free water (Van de Lagemaat and Pyle, 2001). The low moisture content allows only a limited number of microorganisms to use in fermentation, mainly yeast and fungi and some bacteria. Agricultural residues are produced in vast amounts (Wang et al., 2015b) and increased about 5-10% annually worldwide (Wang et al., 2015a), which pose a disposal problem. These wastes can be used in animal nutrition. In recent years, fermentation has been used to utilize the agricultural residues. It can improve the nutritional quality of feedstuffs, eliminate antinutritional components, provide enzyme, phenolic compounds, organic acid and coloring pigments. Fermented feedstuffs can improve performance, feed utilization, digestibility, antioxidant capacity, intestinal microflora and morphology in poultry.

1.Nutritional enrichment It is crucial to meet the nutritional requirement of animal for taking desired yield and animal products. Balanced diet is only be made with feedstuffs having high nutritional quality. But it increases nutrition cost since prices of quality feedstuffs is high. Agricultural wastes can be made quality feedstuff through the fermentation process. Fermentation, generally, increase protein and decrease cellulotic components in the substrate (Table 1).

Table 1. Nutritional enrichment in agricultural wastes through solid state fermentation

Microorganisms	Substrates	CP	EE	Ash	NFE	CF	NDF	ADF	References
Aspergillus niger	Sour cherry kernel	+	+	+	-	-	-	-	Güngör (2018)
Aspergillus niger	Sour cherry kernel	+	=	+	-	=	=	+	Güngör et al. (2017)
Aspergillus niger	Grape seed	+	+	-	-	-	-	-	Altop et al. (2017a)
Aspergillus niger	Olive leave	+	+	+	=	-			Altop et al. (2017b)
Bacillus amyloliquefaciens	Rice bean	+				-			Supriyati et al. (2015)
Candida utilis and Aspergillus niger	Ginkgo biloba leaves	+							Zhang et al. (2015)
Aspergillus niger	Pine needle	+							Wu et al. (2015)
Trichoderma pseudokoningii (ATCC 26801)	Cassava	+							Bayitse et al. (2015)
Laminaria digitata	Seaweed	+							Hou et al. (2015)
Bacillus amyloliquefaciens	Rice bran	+	-	+					Supriyati et al. (2015)
Saccharomyces cerevisiae	Cassava	+							Boonnop et al. (2009)
Rhizopus stolonifer	Palm kernel cake, cassava peel and cocoa pod husk	+	-	+		-			Lateef et al. (2008)
Candida utilis ATCC 9256	Patato waste	+							Gélinas and Barrette (2007)
Aspergillus niger	Palm kernel	+	=			-			Iluyemi et al. (2006)
Aspergillus oryzae MTCC 1846	Rice bran	+							Rudravaram et al. (2006)
Saccharomyces cerevisiae	Cactus pear	+							Araújo et al. (2005)
Neurospora sitophila	Sugar beet pulp, wheat bran and citrus waste	+				-			Shojaosadati et al. (1999)

2. Eliminating antinutritional components Plants contain some components that harm animals such as tannin, gossypol, lectin, trypsin inhibitors etc., which is defined as antinutritional factors (Soetan and Oyewole, 2009).

They decreased nutrient digestibility, showed toxic effect and suppressed growth in animal (Etuk et al., 2012). Many antinutritional factors in agricultural residues such as tannin, phytic acid, HCN acid, lectin and gossypol can be eliminated by solid-state fermentation (Table 2).

Table 2. Elimination of antinutritional factors through solid state fermentation

Microorganisms	Substrates	Antinutritional factors	References
Lactobacillus salivarius	Canola meal	Decreased total glucosinolate	Ahmed et al. (2014)
Aspergillus niger	Cherry kernel	Amygdalin	Chang and Zhang (2012)
Saccharomyces cerevisiae	Cassava	Decreased HCN acid	Boonnop et al. (2009)
Lactobacillus sp. and yeast	Groundnut	Tannin and trypsin inhibitor	Mbata et al. (2009)
Aspergillus niger	Shea nut meal	Hydrolysable tannin	Dei et al. (2008a)
Aspergillus niger and Ceriporiopsis subvermispora	Shea nut meal	Saponin and hydrolysable tannin	Dei et al. (2008b)
Rhizopus stolonifer	Cassava peel	Cyanide	Lateef et al. (2008)
Aspergillus niger	Cottonseed meal	Decreased gossypol	Zhang et al. (2006)
Lactobacillus plantarum	Bean	Chymotrypsin inhibitor and lectin	Martín-Cabrejas et al. (2004)
Lactobacillus acidophilus	Sesame seed meal	Tannin and phytic acid	Mukhopadhyay and Ray (1999)

3. Enzyme production Poultry can not utilize nutrients in the feedstuffs like ruminants because they have not ability to produce some enzymes that break down fibrinolytic compounds. Exogenous enzymes can be used for increasing FCR and taking more animal product by less feedstuff. Plenty of enzymes such as cellulase, xylanase, phytase, lipase and protease can be produced by fermentation (Table 3)

4. Production of phenolic compounds Plants include great numbers of phenolic compounds having antioxidant effect. Antioxidants protect organisms from oxidative stress caused by free radicals. Actually, free radicals are unstable electrons taking action in immune system by killing photogen microorganism and occurring naturally with metabolic reactions in the body (Surai, 2016). It can damage all biological materials such as DNA, protein, lipid and carbohydrate because of being unstable form.

In animal nutrition, phenolic compounds can be used to prevent oxidative deterioration of feed and to protect animal from oxidative stress. However, phenolic compounds are used at a limited level because of being very expensive products (Nolan and O'Connor, 2008). Many phenolic compounds such as catechin, caffeic acid, ellagic acid can be produced from agricultural residues by solid-state fermentation (Table 4).

However, there are some studies presenting a decrease in total soluble phenolics by fermentation (Dei et al., 2008a).

Table 4. Production phenolic compound with solid state fermentation

Microorganisms	Substrates	Compounds	References
Thamnidium elegans	Maize	Gallic acid	Salar et al. (2012)
Kluyveromyces marxianus	Soybean curd residue	Gallic acid	Rashad et al. (2011)
Bacillus pumilus	Soybean	Gallic acid	Cho et al. (2009)
Aspergillus niger	Creosote bush	Gallic acid	Ventura et al. (2009)
Bacillus subtilis	Soybean	Catechin	Juan and Chou (2010)
Bacillus subtilis	Lupinus angustifolious seed	Catechin	Fernandez-Orozco et al. (2008)
Trichoderma harzianum	Soybean seed	Genistin	Singh et al. (2010)
Aspergillus oryzae and Aspergillus awamori	Wheat	Total phenolics content	Bhanja et al. (2009)
Aspergillus niger	Tar bush	Pyrocatechol	Ventura et al. (2009)
Phanerochaete chrysosporium	Pistachio hulls	Caffeic acid	Abbasi et al. (2007)
Saccharomyces cerevisiae	Wheat bran	Ferulic acid	Moore et al. (2007)

5. Organic acid production Organic acids can be used in order to prevent microbiological deterioration of feed and to improve intestinal microflora in poultry. Microorganisms can produce organic acids such as citric acid, succinic acid, lactic acid, oxalic acid (Table 5).

6. Production color pigment Meat and egg yolk color are important factors affecting consumer preference in poultry production (Ofosu et al., 2010). Color pigments which can change product color desired way are produced by microorganisms (Table 6).

Effects of fermented feed on poultry Body weight, egg yield, FCR and nutrient digestibility can be increased by improving nutritional composition, eliminate antinutritional factors in feedstuff and producing enzymes by microorganisms. Producing phenolic compounds can increase antioxidant capacity and producing organic acid can improve intestinal microflora and morphology in poultry (Table 7).

It has been reported that body weight was increased by fermented products of soybean meal (Lee et al., 2010: Mathivanan et al., 2006) shea nut meal (Dei et al., 2008a: Dei et al., 2008b), garlic and onion by-products (Kang et al., 2010) and cherry kernel (Güngör, 2018) in broiler.

Table 3. Enzyme production through solid state fermentation

Microorganisms	Substrates	Enzymes	References
Candida utilis and Aspergillus niger	Ginkgo biloba leaves	Cellulase, hemicellulase, glucosidase	Zhang et al. (2015)
Aspergillus niger	Pine needle	Cellulase, hemicellulase, β-glucosidase	Wu et al. (2015)
Aspergillus niger	Rice rust, rice bran, whey and sugarcane bagasse	Cellulolytic enzymes	Rocha et al. (2013)
Neurospora sitophila	Wheat straw	Cellulase, β-xylosidase, endoglucanases	Li et al. (2013)
Rhizopus stolonifer JS-1008	Corncob	Xylanase	Zhang et al. (2013)
Bacillus subtilis NRC1aza	Starch	Levansucrase	Esawy et al. (2013)
Aspergillus heteromorphus MTCC 8818	Rosewood sawdust	Tannase	Beniwal et al. (2013)
Trichoderma harzianum	Castor oil cake and sugarcane bagasse	Lipase	Coradi et al. (2013)
Aspergillus fumigatus	Wheat straw	Exoglucanase	Mahmood et al. (2013)
Bacillus subtilis GXA-28	Soybean residue	Fibrinolytic enzyme	Zeng et al. (2013)
Aspergillus niger GS1	Corn pericarp	β-xylosidase	Díaz-Malváez et al. (2013)
Natural microflora	Soy fibre residues	Alkaline protease	Abraham et al. (2013)
Bacillus sp. KR-8104	Wheat bran	α-amylase	Hashemi et al. (2013): Hashemi et al. (2010)
Cladosporium sp.	Wheat bran	L-glutaminase	Jesuraj et al. (2013)
Aspergillus niger	Citrus peel	Phytase	Rodríguez-Fernández et al. (2013)
Aspergillus niger	Apple pomace	β-mannanase	Yin et al. (2013)
Pleurotus ostreatus	Sugarcane bagasse	Laccase	Karp et al. (2012)
Trichoderma koningii	Wheat bran and chitosan	Chitosanase	da Silva et al. (2012)
Oerskovia xanthineolytica	Wheat bran and chitosan	Chitinase	Waghmare et al. (2011)
Colletotrichum lindemuthianum	Shrimp shell chitin waste and wheat bran	Chitin deacetylase	Suresh et al. (2011)
Aspergillus oryzae MTCC 5341	Wheat bran	Acid protease	Vishwanatha et al. (2010)
Aspergillus foetidus MTCC 4898	Wheat bran	Xylanase	Chapla et al. (2010)
Thermomyces lanuginosus 195	Wheat bran	Xylanase	Gaffney et al. (2009)
Aspergillus caespitosus	Wheat bran	Invertase	Alegre et al. (2009)

Body weight gain was also increased by fermented Artemisia princeps (Kim et al., 2012), rice bran (Supriyati et al., 2015), cottonseed meal (Nie et al., 2015) and Ginkgo biloba leaves (Zhang et al., 2015).

Ginkgo biloba leaves also increased egg yield after fermentation (Zhao et al., 2013). In contrast, Dei et al. (2008a) reported a suppression on body weight in broiler with dietary inclusion of fermented shea nut.

Table 5. Organic acid production through solid state fermentation

Microorganisms	Substrates	Organic acids	References
Aspergillus niger NRRL 567	Apple pomace	Citric acid	Dhillon et al. (2013)
Aspergillus niger NRRL 567 and NRRL 2001	Apple pomace	Citric acid	Dhillon et al. (2011)
Aspergillus niger NRRL 567	Peat moss	Citric acid	Barrington et al. (2009)
Aspergillus niger	Banana peel	Citric acid	Karthikeyan and Sivakumar (2010)
Aspergillus niger NRRL 567 and NRRL 328	Orange and pineapple wastes	Citric acid	Kuforiji et al. (2010)
Aspergillus awamori, Aspergillus oryzae and Actinobacillus succinogenes	Wheat bran	Succinic acid	Du et al. (2008)
Aspergillus niger, Aspergillus awamori and Aspergillus oryzae	Wheat flour and bran	Succinic acid	Dorado et al. (2009)
Aspergillus awamori and Aspergillus oryzae	Waste bread	Succinic acid	Leung et al. (2012)
Lactobacillus strains	Pine needle	Lactic acid	Ghosh and Ghosh (2011)
Lactobacillus plantarum MTCC 6161	Tea waste	Lactic acid	Gowdhaman et al. (2012)
Lactobacillus plantarum MTCC 1407	Cassava residue	Lactic acid	Ray et al. (2009)
Phanerochaete chrysosporium	Straw	Oxalic acid	Li et al. (2011)

Table 6. Production of pigments with solid state fermentation

Microorganisms	Substrates	Pigments	References
Monascus purpureus CMU001	Cornmeal	Red	Nimnoi and Lumyong (2011)
M. sanguineus and M. purpureus MTCC410	Rice	Red	Dikshit and Tallapragada (2012)
Monascus purpureus KACC 42430	Corn cob	Red	Velmurugan et al. (2011)
Monasus ruber	Rice	Orange, yellow and red	Vidyalakshmi et al. (2010)
Monascus purpureus	Rice	Lovastatin	Panda et al. (2009)
Penicillium sp. NIOM-02	Wheat	Red	Dhale and Vijay-Raj (2009)
Rhodotorula glutinis DM 28	Rice bran	β-carotene	Roadjanakamolson and Suntornsuk (2010)
Monascus pilosus NBRC4520	Rice	Red-lovastatin	Tsukahara et al. (2009)

Feed conversion ratio (FCR) was improved through fermented soybean meal (Feng et al., 2007: Mathivanan et al., 2006), Ginkgo biloba leaves (Yu et al., 2015: Zhang et al., 2015), rice bran (Supriyati et al., 2015) and sour cherry kernel (Güngör, 2018) in broiler and improved by fermented soybean meal (Xu et al., 2012a) and Ginkgo biloba leaves (Zhao et al., 2013) in laying hen. Fermented products can increase Lactobacillus in broiler cecum (Güngör, 2018: Kang et al., 2010: Sun et al., 2013a: Sun et al., 2013b) and ileum (Kim et al., 2012: Sun et al., 2013a: Sun et al., 2013b: Zhang et al., 2015) and also laying hen ileum and cecum (Zhao et al., 2013). Bifidobacteria can be increased in laying hen ileum and cecum (Zhao et al., 2013). Fermented feedstuffs can also decrease pathogen microorganisms in intestine. E. coli was decreased in broiler ileum and cecum (Sun et al., 2013a: Sun et al., 2013b: Zhang et al., 2015) and laying hen ileum (Zhao et al., 2013). Moreover, Salmonella was decreased broiler ileum and cecum (Zhang et al., 2015: Zhao et al., 2013). Intestinal morphology can be also affected by fermented feedstuffs. They increased villus height of broiler duodenum (Xu et al., 2012b: Yu et al., 2015: Zhang et al., 2015), jejunum (Xu et al., 2012b: Zhang et al., 2015), ileum (Mathivanan et al., 2006), villus height of laying hen duodenum and jejunum (Xu et al., 2012a), villus width in broiler ileum (Mathivanan et al., 2006), decreased crypt depth of broiler jejunum (Zhang et al., 2015) and also increased villus height:crypt depth in broiler duodenum (Xu et al., 2012a: Yu et al., 2015), jejunum (Yu et al., 2015) and laying hen duodenum and jejunum (Xu et al., 2012a)

Protease and amylase activities were increased through the inclusion of fermented cottonseed meal (Sun et al., 2013a) and Ginkgo biloba leaves (Yu et al., 2015). Besides, Mathivanan et al. (2006) reported that fermented soybean meal increased lipase activity. These results suggest that fermented products can increase digestibility in poultry. Thus, fermented products increased digestibility of dry matter, crude protein, organic matter and ash in broiler (Güngör, 2018: Nie et al., 2015).

Improving immune response is necessary to prevent poultry diseases. Nutritional regulation can enhance the immunity (Kogut, 2017). Fermented feedstuffs increased IgG, IgM and IgA in broiler (Ao et al., 2011: Feng et al., 2007: Xu et al., 2012b), IgG, IgA in laying hen (Xu et al., 2012a) and IgG, IgM in duck (Fazhi et al., 2011).

Fermented feedstuffs can also affect mineral metabolism in poultry. Serum phosphorus level was increased in broiler (Feng et al., 2007: Xu et al., 2012b), laying hen (Xu et al., 2012a) and duck (Fazhi et al., 2011). It also increases serum Ca level in broiler (Xu et al., 2012b) and duck (Fazhi et al., 2011).

Decrease in serum urea nitrogen level may indicate increased protein availability (Yu et al., 2015). Fermented feedstuff decreased serum urea nitrogen in broiler (Feng et al., 2007: Xu et al., 2012b: Yu et al., 2015) and laying hen (Xu et al., 2012a). It can be said fermented feedstuffs can improve protein utilization in poultry. Lipid metabolism of poultry can be affected by fermented feedstuffs. It decreased cholesterol level in serum (Ao et al., 2011: Lee et al., 2010: Zhao et al., 2013) and egg yolk (Fujiwara et al., 2008: Yu et al., 2015: Zhao et al., 2013). It also decreased triglyceride in serum (Ao et al., 2011), liver (Nie et al., 2015) and egg yolk (Zhao et al., 2013).

Moreover, it has been reported a decrease in abdominal fat (Nie et al., 2015), egg yolk LDL and an increase in egg yolk HDL (Zhao et al., 2013). Fermentation can provide antioxidant effect to feedstuffs. Lateef et al. (2008) reported that fermentation increased radical scavenging activity of cassava peel. Malondialdehyde (MDA) in serum (Wu et al., 2015), liver (Wu et al., 2015), breast meat (Ao et al., 2011: Kim et al., 2012) and tight meat (Kim et al., 2012) were decreased by fermented products. SOD was increased in serum, liver (Wu et al., 2015), jejunum and ileum (Zhang et al., 2015). GSH was also increased in jejunum and ileum (Zhang et al., 2015).

While fermentation can provide color pigments to feedstuff (Roadjanakamolson and Suntornsuk, 2010), coloring effect on poultry products has not been seen in examined studies. Fermented soybean and garlic powder have been reported to have no effect on egg yolk color (Fujiwara et al., 2008: Lee et al., 2010) and breast meat color (Ao et al., 2011), respectively.

In conclusion, fermentation can be used to improve the nutritional quality of feedstuffs, eliminate antinutritional components and produce enzyme, phenolic compounds, organic acid and coloring pigments. These functions of fermentation can improve performance, FCR, nutrient digestibility, intestinal microflora, morphology and increase antioxidant capacity in poultry.

However, although fermentation can increase color pigment in feedstuff, there was no observed changes in product color. There is a need for detailed studies on this area to confirm the results of previous studies and illuminate future of the feed fermentation in poultry nutrition.

Table 7. Effect of fermented feeds on poultry

Animal	Microorganisms	Feed	Effect of the experiment	References
Broiler	Aspergillus niger	Sour cherry kernel	Increased BW Improved FCR Increased digestibility Higher Lactobacillus (cecum)	Güngör (2018)
Broiler	Bacillus amyloliquefaciens	Rice bran	Increased BWG Improved FCR	Supriyati et al. (2015)
Broiler	Candida tropicalis	Cottonseed meal	Increased BWG Increased digestibility (dry matter, crude protein, ash) Decreased abdominal fat and triglyceride (liver)	Nie et al. (2015)
Broiler	Candida utilis and Aspergillus niger	Ginkgo biloba leaves	Increased BWG Improved FCR Decreased MDA (liver) Higher SOD, GSH (jejunum and ileum) Higher villus height (duodenum and jejunum) Lower crypt depth (jejunum) Increased Lactobacillus spp. (ileum) Decreased E. coli and Salmonella (ileum and cecum)	Zhang et al. (2015)
Broiler	Aspergillus niger	Pine needle	Higher SOD (serum and liver) Higher antioxidant capacity Decreased MDA (serum and liver)	Wu et al. (2015)
Broiler	Bacillus subtilis var. natto and Bacillus licheniformis	Ginkgo biloba leaves	Improved FCR Higher protease and amylase Higher villus height (duodenum) Higher villus height:crypt depth (duodenum and jejunum) Decreased serum urea nitrogen	Yu et al. (2015)
Broiler	Bacillus subtilis BJ-1	Cottonseed meal	Higher Lactobacillus spp. (ileum and cecum) Lower E. Coli (ileum and cecum) Increased amylase and protease activity	Sun et al. (2013a) Sun et al. (2013b)
Broiler	Lactobacillus fermentum Bacillus subtilis	Rapeseed meal	Higher IgG, IgM, phosphorus and calcium Higher villus height (duodenum and jejunum) Higher villus height:crypt depth (jejunum) Decreased serum urea nitrogen	Xu et al. (2012b)
Broiler	Weissella koreensis	Garlic powder	Higher IgG (serum) Lower MDA (breast meat) Decreased cholesterol, triglyceride (serum)	Ao et al. (2011)
Broiler	Lactobacillus plantarum	Garlic and onion by-products	Increased BW Higher lactobacillus (cecum)	Kang et al. (2010)
Broiler	Monascus purpureus	Soybean	Increased BW Lower cholesterol (serum) and cook loss	Lee et al. (2010)

Broiler	Aspergillus niger and Ceriporiopsis subvermispora	Shea nut meal	Increased BW	Dei et al. (2008a): Dei et al. (2008b)
Broiler	Aspergillus niger	Soybean meal	Increased BW and improved FCR Increased villus height and width (ileum) Increased lipase activity	Mathivanan et al. (2006)
Broiler	Aspergillus oryzae	Soybean meal	Increased BW and improved FCR Higher IgA, IgM Higher plasma phosphorus level Decreased serum urea nitrogen	Feng et al. (2007)
Brown male chickens	Lactobacillus	Artemisia princeps	Increased BWG Decreased MDA (breast and thigh) Higher Lactobacillus spp. (ileum)	Kim et al. (2012)
Laying hen	Candida utilis and Aspergillus niger	Ginkgo biloba leaves	Increased egg yield Improved FCR Lower cholesterol, triglyceride, LDL (egg yolk) Increased HDL (egg yolk) Increased Lactobacillus spp. and Bifidobacteria (ileum and cecum) Decreased E. coli (ileum) Decreased Salmonella (ileum and cecum)	Zhao et al. (2013)
Laying hen	Bacillus licheniformis	Soybean meal	Improved FCR Higher IgA, IgG and phosphorus (serum) Higher villus height (duodenum and jejunum) Higher villus height: crypt depth (jejunum) Decreased serum urea nitrogen	Xu et al. (2012a)
Laying hen	Bacillus ligniformis	Soybean	Lower cholesterol (egg yolk)	Fujiwara et al. (2008)
Duck	Lactobacillus plantarum and Bacillus subtilis	Rapeseed meal	Higher IgG, IgM, total phosphorus and calcium (serum)	Fazhi et al. (2011)

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