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Review

Potential of bacterial fermentation as a biosafe method of improving feeds for pigs and poultry

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The use of fermented liquid feeds in monogastric animal nutrition is regarded as one of the biosafe methods of animal production. This paper examines bacterial fermentation of feed substrates for production of fermented liquid feeds for pigs and moist feeds for poultry. Emphasis is placed on the interplay of factors affecting feed fermentation and their relationship to feed quality. The resistance of fermented feeds to enteropathogenic contamination prior to feeding and their potential contribution to African agriculture is highlighted.

Key words: Fermented liquid feed technology, pigs, poultry.

INTRODUCTION

There is considerable concern over the use of antibiotic growth promoters (AGPs) in animal production. Their extensive usage has resulted in the selection for survival of resistant bacteria species or strains (Doyle, 2001; Montagne et al., 2003; Khaksefidi and Rahimi, 2005). This resistance can be transferred to other previously susceptible bacteria and can be hazardous to both animal and human health (Montagne et al., 2003).

The use of in-feed AGPs has been banned in the European Union (Wilkie et al., 2005; Williams et al., 2005) and there are further attempts to reduce or remove in-feed AGPs worldwide (Jin et al., 1998; Yegani and Korver, 2008) . This would have significant implications on gut microbial profiles (Yegani and Korver, 2008) as well as increase competition between gut microflora and the host for available nutrients (Dibner and Richards, 2005).

However, there is an active search for alternatives to AGPs in animal feeding. This includes the use of probiotics, organic acids, prebiotics, minerals, enzymes, herbs, phenolic aromatic components and fermented feeds (FF) (Knarreborg et al., 2002; Reid and Friendship, 2002; Verstegen and Williams, 2002; Dahiya et al., 2006; Steiner, 2006; Missotten et al., 2007). FF is considered as a biosafe method for replacing AGP in pigs (Knarreborg et al., 2002; Kobashi et al., 2008) and poultry (e.g. Heres et al., 2003a; Heres et al., 2003b; Heres et al., 2003d; Niba, 2008). FFs are characterised by high numbers of lactic acid bacteria (LAB) (approximately 10^9 cfu/ml of feed) and high concentrations of lactic acid (>150 mM) (Heres et al., 2003a; Niba, 2008). In chickens, the organic acid content of fermented feeds has been reported to improve foregut barrier function against pathogens by increasing acidity and lowering the pH (Heres et al., 2003d; Engberg et al., 2006). The proportion of chlortetracycline-resistant *Escherichia coli* strains was significantly reduced in the gut of weaned piglets fed fermented liquid feed (FLF) (22.2%) compared with dry feed (88.9%) (Kobashi et al., 2008). This review, examines the potential of bacterial fermentation of feeds as a means of improving feeds for pigs and poultry. Emphasis will be placed on the interplay of factors affecting feed fermentation and their relationship to feed quality.

FERMENTED LIQUID FEED TECHNOLOGY

Man has known the use of microbes for preparation of food products for thousands of years and all over the world a wide range of fermented foods and beverages contribute significantly to the diet of many people (Achi, 2005). The use of liquid feeds in animals has created an

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opportunity for recycling of liquid co-products from the human food industry especially in the European pig industry (Scholten et al., 1999; Brooks et al., 2003a). This has considerably reduced the need for alternative methods of disposal of these products, like drying, disposal to land fill or burning (Scholten et al., 1999).

However, liquid feeds have the potential to serve as potent reservoirs of enteropathogens unless steps are taken to prevent their introduction and proliferation during storage and feeding (Beal et al., 2002). Brooks et al. (2001) also stated that liquid- feeding systems can easily become contaminated. They further observed that the development of computerised liquid-feeding systems capable of feeding pigs *ad libitum* has rekindled interest in the possibility of liquid feeding for weaner pigs. This, in addition to recent developments in the use of lactic acid bacteria in the accelerated fermentation of feed substrates for animal feeding as well as reducing the possibility of contamination by enteropathogens (Beal et al., 2002; Beal et al., 2005), has provided a good basis for improvement in pig nutrition. It is also having much promise in other farm animal species especially poultry (Heres et al. , 2003b; Skrede et al., 2003; Niba, 2008) and aquaculture (Refstie et al., 2005) . Fermented liquid feed technology could make important contributions to African agriculture especially in semi-arid and hot areas (Niba et al., 2008b). In such areas, ambient temperatures (appro-ximately 30°C) could support efficient lactic acid fermentation of feeds (Beal et al., 2002; Niba, 2008). Furthermore, wet feeding in hot climates has been shown to improve feed intake and growth rates in poultry (Forbes, 2003).

According to Beal et al. (2002), lactic acid bacterial fermentation of feeds provides a feed that has a pH of 3.8 - 4.0 and contains 150 - 250 mmol/L lactic acid. A similar range of fermented feed pH has been reported by Geary et al. (1996) (3.8 - 4.2), Christensen et al. (2007) (3.6 - 4.2), Scholten et al. (1999) (3.5 - 4.5) and Moran et al. (2006) (<3.8). The synergistic effect of a high lactic acid concentration and low pH is believed to act in concert to give fermented feeds their antimicrobial activity. This enables them to withstand contamination by pathogens like *Salmonella* spp. (Geary et al., 1996; van Winsen et al., 2001a; Beal et al., 2002; van Winsen et al., 2002), *Campylobacter* spp. (Heres et al., 2004), and coliforms (Russell et al., 1996).

The mechanism of action of fermented feeds and fermented co-products in controlling enteropathogens both *in vitro* and *in vivo* has been reviewed extensively (Brooks et al., 1996; Scholten et al., 1999; Hansen et al., 2000; van Winsen et al., 2001a; Beal et al., 2002; Demeckova et al., 2002; Hojberg et al., 2003; Boesen et al., 2004; van Immerseel et al., 2004; Beal et al., 2005; Moran et al., 2006). The antimicrobial effects of lactic acid are believed to be exerted by the ability of the undissociated acid to gain entry into the cell, disrupt pH homeostasis and consequently cause nucleic acid and protein damage (Beal et al., 2002). According to Moran (2001), the low pH, dissociation constant (pKa value),and the molar concentration are factors that determine the inhibitory activity of lactic and acetic acid in fermented feed. While inside the cell, the acid dissociates and causes a drop in pH. This stops enzymatic processes and causes the proton motive force to collapse. The anion may also destroy the cell wall resulting in cell death (van Winsen et al., 2001a; van Winsen et al., 2001b). However, Alakomi et al. (2000) earlier stated that disruption of the outer membrane by acids could involve both dissociated and undissociated forms. As indicated, the likely action on the outer membrane of *Salmonella* could be protonation of anionic components such as carboxyl and phosphate groups. This consequently weakens the molecular interactions between outer membrane components thus increasing its permeability.

In a recent review by Brooks (2008) on fermented liquid feeds for pigs, increasing feed cost, withdrawal or reduction of antimicrobial growth promoters (AGP) in feeds and quality assurance programmes related to *Salmonella* in pig meat were given as reasons why producers should adopt liquid feeding. However, he indicated that the success of liquid feeding depended on;

i.) Microbial fermentations and selection of LAB capable of generating lactic acid levels above 100 mmol/L that can significantly reduce numbers of enteropathogens and the incidence of *Salmonella*.
ii.) Batch fermentation of the cereal portion of feeds with inoculants capable of generating high lactic acid concentrations to give more consistent results of fermentation.
iii.) Fermentations that could preserve the feed, improve the availability of nutrients, reduce the level of anti-nutrients and have LAB with probiotic properties.

Meanwhile, the three principal components involved in the fermentation process are the fermenting micro-organisms, the feed substrate and the enabling environment for fermentation (Figure 1).

INFLUENCE OF MICRO-ORGANISM AND FEED SUBSTRATE ON FERMENTATION

The selection of LAB for feed fermentation to meet desired feed and production objectives has been highlighted in previous reviews (Brooks et al., 2003b; Brooks, 2008) . The choice of feed substrates to obtain high numbers of LAB (10^9 cfu/g feed) and levels organic acids (>150 mmol/L) or a consistent fermentation product has also been researched (Canibe et al., 2007a; Niba et al., 2007; Lyberg et al., 2008; Niba, 2008; Niba et al., 2008b; Olstorpe et al., 2008) or reviewed (Brooks, 2008). Fermentation objectives that have influenced the use of LAB have centred on;

i.) Selection for rapid production of organic acids (mainly lactic acid) to ensure biosafety (e.g. Missotten et al.,

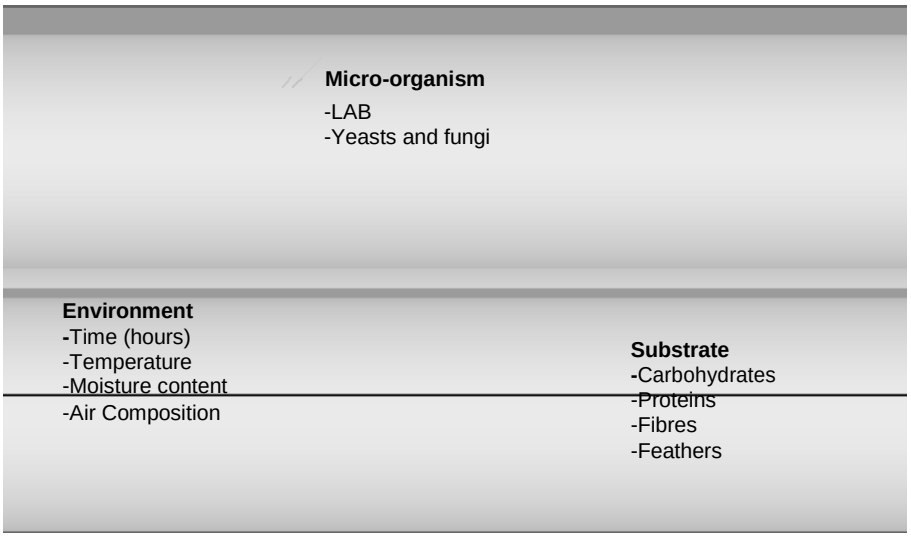

Figure 1. Interactions in the fermentation medium. Fermentation conditions influence rate of fermentation, type of microbe and substrate quantity and quality affects the medium.

2007; Missotten et al., 2008).
ii.) Selection for homolactic fermentation to improve feed palatability.
iii.) Breakdown of anti-nutrients and increased bioavailability of nutrients (e.g. Bertsch et al., 2003; Brooks et al., 2003a; Oboh, 2006; Skrede et al., 2007; Lyberg et al., 2008; Okpako et al., 2008).

A summary of how some of these objectives relate is shown in Table 1.

The advantages of fermenting feeds can be summarised from the table as follows;

i.) Reduction in the level of anti-nutrients within the feed.
ii.) Improved bioavailability of minerals (e.g. P, Ca, Mg and Cu).
iii.) Increase in protein contents (lysine, histidine and methionine).
iv.) Breakdown of indigestible carbohydrates.

INFLUENCE OF FERMENTATION LENGTH AND CONDITIONS

The length of steeping feed ingredients, the type of feed substrates and fermentation conditions influence the quality of the fermentation product. Steeping time has been related to its effects on the activity of endogenous enzymes and the breakdown of anti-nutrients within the grain. According to Choct et al. (2004a) the effects on growth and feed intake for weaner pigs resulting from steeping of feed for 15 h might be related to the release and activation of endogenous enzymes in the grain. The activation of these enzyme systems within the grain can act on cell wall structures in a similar way to exogenous feed enzymes (Choct et al., 2004b). In reviewing the effect of steeping in liquid feeding systems, Brooks et al. (1996) indicated that phytases that were naturally present in the pericarp of some grains (like cereals) could be activated by soaking. They also stated that soaking feed for 8 - 16 h before feeding increased the bioavailability of phosphorus, calcium, magnesium and copper. In another study (Lyberg et al., 2008), the phytase activity for a cereal grain mix of wheat, barley and triticale was 1382 FTU /kg DM and inositol hexaphosphate bound-phosphorus and total phosphorus were 2.2 and 3.7 g/kg DM. After fermentation, dietary inositol hexaphosphate was completely degraded to release phosphorus.

Fermentation of the carbohydrate-rich cereal components of the diet separately and combining them with the protein-rich components just before feeding has some practical and nutritional advantages (Beal et al., 2002; Brooks et al., 2003b; Beal et al., 2005; Moran et al., 2006; Canibe et al., 2007a; Brooks, 2008). Fermenting the protein rich components produces undesirable end-products, such as biogenic amines, which could affect the palatability of fermented liquid feed (Canibe et al., 2007a). Furthermore, some studies have reported the degradation of free amino acids added to diets during fermentation (Handoyo and Morita, 2006; Canibe et al., 2007b). However, Niven et al. (2006) demonstrated that the loss of lysine from fermented liquid pig feed was due to metabolism of lysine by *E. coli* present in the feed rather than its utilisation as an energy source by LAB. It was observed that inoculation of feed with LAB and 50 mmol/L lactic acid at the beginning of fermentation resulted in lysine levels remaining unaltered after 72 h fermentation. The addition of acid reduced or eliminated the *E. coli* and allowed the lysine to remain intact during

Table 1. Effect of micro-organisms and feed substrates on feed fermentation.

Fermentation type	Substrate	pH	Lactic acid or effects on diet	Acetic acid or effects on diet	Ethanol or effects on diet	Source
L. plantarum, *P. pentosaceus*, Yeasts	Wheat and wheat by-products	<3.8 4.53	<60† 22.21*	<10† 22.42*	<10† 9.12*	(Moran et al., 2006) (Beal et al., 2005)
Spontaneous fermentation. (LAB and Yeasts)	Barley	4.30	34.43*	27.34*	10.74*	(Beal et al., 2005)
Lactobacillus brevis	Soybean white flakes	4.8	Elimination of indigestible carbohydrates and lowered trypsin inhibitor activity			(Refstie et al., 2005)
Lactobacillus sp. (strain AD_2), *L. plantarum* (AM4).	Barley and wheat and barley whole meal flours	-	Significant reduction in phytic acid, dietary fibre and -glucans (33.5-18.4 g/kg in barley), alpha-amylase activity in barley			(Skrede et al., 2001; Skrede et al., 2002; Skrede et al., 2003; Skrede et al., 2007)
Lactobacillus acidophilus	Sesame seed meal	-	Phytic acid reduced to below detectable limits and tannin contents reduced from 20 to 10 g/Kg			(Mukhodhyay and Ray, 1999)
Lactobacillus plantarum	Complete diets of cereals and soybean meal	3.6	Reduction in feed dry matter and insoluble non-starch polysaccharides, increased viscosity of feed			(Christensen et al., 2007)
Unspecified *in vitro* fermentation (LAB and yeasts)	Pig grower diet	4.9-5.3	Reduced contents of total and free lysine (g/kg crude protein, threonine and methionine			(Canibe et al., 2007c)
LAB fermentation	Phytic acid in cereals	-	Increase in apparent bioavailability of Phosphorus, Calcium, Magnesium and Copper			(Brooks et al., 2001; Brooks, 2008)
	Fermented fish silage supplementation in quail diet		Increase in egg production and quality (Haugh unit)			(Zynudheen et al., 2008)
Kocuria rosea	Poultry feathers (fermented feather meal)	-	Improved content and availability of amino acids, lysine 3.46%, histidine 0.94%, methionine 0.69%.			(Bertsch et al., 2003; Bertsch and Coello, 2005)
Aspergillus nigeir and *L. rhamnosus*	Cassava peel meal	-	Increase in proteins (24.4%), ash (7.52%), crude fibre (10.62%) and decrease in cyanide (7.35 mg/kg)			(Okpako et al., 2008)
Saccharomyces cerevisae and *Lactobacillus* spp.	Cassava peel meal	-	Increase in protein content (21.5%) and decrease in cyanide (6.2 mg/kg), and phytate (789.7 mg/100 g).			(Oboh, 2006)

†g/kg dry matter, *mmol/L, WDG-wet wheat distiller's grain.

the fermentation process.

The main goal of fermentation is a high lactic acid concentration (>150 mmol/L) and a low pH (<4.5). Temperature affects fermentation rate and low temperatures may yield insufficient quantities of fermentation end-products. According to Carlson and Poulsen (2003) an increase in fermentation temperature from 10 to 20°C improved the proportion of total barley phytate that was degraded during an 8 h fermentation from 48 to 55%. Corresponding values for total wheat phytate degraded were 52 and 62%. At 38°C it required 2 h for 72% of the total phytate to be degraded. Fermentation of a cereal grain mix at 10°C produced 8.6 gl^{-1} of lactic acid compared with 13.6 gl^{-1} at 20°C (Lyberg et al., 2008). At low temperatures yeast predominates and produces ethanol (Brooks, 2008). Insufficient lactic acid concentra-

tion with 24 h fermentation cycles which are more practical on farms may be the case at low temperatures. Furthermore, spontaneous fermentation of a cereal grain mix at 10°C required 7 days for the pH to drop to 4.0 compared with 5 days for 15 and 20°C. Prolonged fermentation also results in considerable variation in species composition of fermented pig feed (Olstorpe et al., 2008). Fermentation at 30°C seems ideal as at 35 and 40°C there was no significant effect on lactic utilisation of feed nutrients like added synthetic lysine by and acetic acid concentrations (Table 2) while butyric acid and ethanol concentrations were significantly increased (Beal et al., 2005). Lactic acid fermentation of sorghum and maize at 30°C produces high levels of lactic acid (>150 mmol/L) as fermented cereal-base for moist chicken feed (Niba, 2008; Niba et al., 2008a; Niba et al., 2008b).

LIQUID TO FEED RATIOS

An important aspect of a successful liquid feeding regime is the liquid to feed ratio of the diet. This affects the dry matter content of diet and may also have implications for the intake and organic acid concentration of the feed. Research to confirm the ideal dry matter content of liquid diets is limited (Choct et al., 2004a). In pigs, a wide range of liquid to feed ratios (3:1, 4:1) (Choct et al., 2004a), (2:1) (Demeckova et al., 2002; Choct et al., 2004a; Xuan Dung et al., 2005), (2.5:1)(Russell et al., 1996; Boesen et al., 2004), (3.5:1) (Geary et al., 1996) have been used. In chickens, these ratios have been reduced to 1.3:1 (Yasar and Forbes, 1999) and 1.4:1 (Heres et al., 2003a; Heres et al., 2003b; Heres et al., 2003c; Heres et al., 2003d; Heres et al., 2004). With lower liquid to feed ratios, fermented chicken feeds could be considered as fermented moist feeds rather than liquid feeds (Niba, 2008). However, the DM concentration of feed has been shown to have little overall effect on the pattern of microbial activity (Geary et al., 1996). Meanwhile, increasing water to feed ratios improved both DM and energy digestibility of diets for pigs. However, since in commercial practice with pigs liquid to feed ratios can vary from 2:1 to 7:1 (Choct et al., 2004a), performance is likely to be affected by DM intake (Table 3).

CONTROLLED FERMENTATION USING STARTER CULTURES

Successful fermentation results have also been found to be dependent on the type of fermentation adopted. A brief definition of the methods of fermentation is given in Table 4. Spontaneous (Beal et al., 2005), backslopping (Moran et al., 2006), inoculated or controlled fermentations (e. g. Christensen et al., 2007; Canibe et al., 2008) have been investigated as methods that could be used for production of fermented liquid feeds. Spontaneous fermentation has been discouraged (Brooks et al., 2003b; Brooks, 2008) because in this system yeast, which can tolerate low pH and a low temperature, can predominate. Yeast fermentation of starch will result in alcohol and carbon dioxide production. The production of CO_2 represents a loss of feed dry matter and energy value. Such feeds could be unpalatable due to 'off' flavours resulting in reduced feed intake. Secondly, spontaneous fermentation may not guarantee a rapid build-up of lactic acid in the feed, which is necessary for biosafety of the feed and to limit the pathogens (Niven et al., 2006). Lastly, since feed ingredients differ in their load of natural microflora, spontaneous fermentation of the same raw material at different times results in inconsistent end-products.

Backslopping has been practiced on many farms (Beal et al., 2002). The limitations of this method have recently been highlighted in the review by Brooks (2008). In addition to these limitations, additions of fresh feed to a dynamic fermenting medium could have adverse implications on microbial balance and the ability of the feed to resist enteropathogens. Temperature shifts during addition that are outside the optimal range of particular pathogens could provoke the secretion of cold-shock proteins (Beal et al., 2002). Such cold shock proteins could increase pathogen tolerance to lactic acid in feed fermented at 20°C compared with 30°C.

Controlled fermentation or inoculated fermented liquid feed would appear preferable for production of fermented liquid feeds for pigs or fermented moist feeds for chickens because more predictable results could be obtained. Selection for LAB that produce lactic acid rapidly, with high 24 h lactic acid (>150 mmol/L) contents (Brooks, 2008), should be the primary objective. The selection of LAB for other factors, such as probiotic properties is beyond the scope of this review.

EFFECTS OF FERMENTED FEED ON PERFORMANCE OF PIGS

In growing pigs, the daily weight gains (kg/day) of FLF fed groups (0.572) and acidified feed (AF) fed groups (0.567) were significantly higher ($P < 0.05$) than pigs on a dry diet (DF) (0.515) and non-fermented liquid feed (NFLF) (0.498) (Xuan Dung et al., 2005). Plasma urea nitrogen was also significantly lower ($P < 0.05$) in FLF fed pigs than the dry diet, non- FLF and AF. As observed by Demeckova (2003), piglets from gilts fed FLF were 300 and 450 g heavier than piglets from the gilts fed NFLF ($P < 0.01$) and DF fed gilts ($P < 0.001$).

Demeckova et al. (2002) reported that faeces from sows fed FLF feed had significantly ($P < 0.001$) lower numbers of coliforms than sows fed NFLF or DF. They also reported that piglets from sows fed FLF excreted faeces that were higher in LAB (7.7 vs 7.3 $\log_{10}$ cfu/g, $P < 0.01$) and lower coliforms (7.5 vs 8.1 $\log_{10}$ cfu/g, $P < 0.001$) than faeces from piglets of DF-fed dams. Further-

Table 2. Effect of incubation time and fermentation temperature on feed fermentation.

Incubation time (h)	Temperature (°C)	pH	Lactic acid or effects on diet	Acetic acid or effects on diet	Ethanol or effects on diet	Source
24	-	3.75	54.5[†]	Yeast population increases 10- fold	Yeast population increases 10- fold	(Moran et al., 2006)
48	-	3.65	Yeasts population stabilizes and coliforms eliminated mainly by backslopping	Yeasts population stabilizes and coliforms eliminated mainly by backslopping	Yeasts population stabilizes and coliforms eliminated mainly by backslopping	
24	-	4.69	11.68*	17.22*	6.81*	(Beal et al., 2005)
48	-	4.34	31.92*	27.55*	10.62*	
72	-	4.21	46.14*	30.75*	12.79*	
-	30	4.47	30.16*	16.42*	11.69*	
-	35	4.41	25.29*	26.57*	9.78*	
-	40	4.36	28.64*	32.89*	8.42*	
48	20	4.2	115*	$D_{value\ (min)}$-250		(Beal et al., 2002)
72	20	3.9	164*	$D_{value\ (min)}$-164		
96	20	3.8	167*	$D_{value\ (min)}$-137		
48	30	3.8	161*	$D_{value\ (min)}$-45		
72	30	3.8	196*	$D_{value\ (min)}$-38		
96	30	3.8	203*	$D_{value\ (min)}$-34		
0[a]	10	-	ND[b]	5.5[c]		(Olstorpe et al., 2008)
0[a]	15	-	ND[b]	5.5[c]		
0[a]	20	-	ND[b]	5.5[c]		
3[a]	10	-	ND[b]	ND[c]		
3[a]	15	-	ND[b]	5.3[c]		
3[a]	20	-	2.1[b]	5.6[c]		
5[a]	10	-	ND[b]	3.8[c]		
5[a]	15	-	2.1[b]	4.6[c]		
5[a]	20	-	3.1[b]	4.9[c]		
7[a]	10	-	2.0[b]	4.5[c]		
7[a]	15	-	2.1[b]	6.2[c]		
7[a]	20	-	2.1[b]	5.7[c]		
0	20	-	<3.0±0.00[c]	5.0±1.27[d]	3.9±0.00[b]	(Canibe et al., 2007c)
6	20	-	<3.0±0.00 [c]	6.0±0.12 [d]	<3.2±0.21 [b]	
24	20	-	8.1±0.75[c]	7.1±0.56[d]	3.6±0.16[b]	
48	20	-	9.5±0.34[c]	6.7±0.87[d]	3.7±0.95[b]	
0	20	-	ND	4.7±0.03	ND	
6	20	-	ND	4.9±0.16	1.9±0.11	
24	20	-	ND	5.9±0.42	6.8±0.14	
48	20	-	91.2±27.66	20.9±6.21	15.5±1.31	
17-19[a]	10		1.8	10.4	1.2	(Lyberg et al., 2008)
17-19[a]	15		1.9	10.4	1.2	
17-19[a]	20		2.2	10.5	1.1	
17-19[a]	10		3.3[b]	7.2[c]	2.4[d]	
17-19[a]	15		3.2[b]	5.9[c]	2.3[d]	
17-19[a]	20		4.8[b]	7.4[c]	2.0[d]	

[†]g/kg dry matter, *mmol/L, $D_{value\ (min)}$-decimal reduction time (minutes) of *Salmonella* in fermented feed, [a]days, [b]yeasts counts (cfu/g feed), [c]LAB counts (cfu/g feed), [d]Enterobacteriaceae counts (cfu/g feed), [d]moulds, ND-not detected.

Table 3. Effect of liquid to feed ratios of diets on performance.

Liquid to feed ratio	Type of operation	Remarks	Source
2:1, 3:1,4:1	Experimental trial	No significant effect on growth and performance parameters but FCR* of liquid diets higher (P<0.05) than dry weaner pig diets.	(Choct et al., 2004b)
1.63: 1 to 3.25:1	Experimental trial	Digestibility coefficient increase from 0.791 to 0.829 with increase in liquid to feed ratio in pigs.	(Barber et al., 1991)
1.5:1 to 2.25:1	Experimental trial	Feed intake, weight gain and carcass weights of chickens not significantly affected.	(Yalda and Forbes, 1995)
2.1:1 to 5:1	Commercial farms	Good results with pigs.	(Choct et al., 2004b)
1.5:1 to 3:1	Experimental trial	No significant effect on pig performance	(Hurst, 2002)
†DM 149 to DM 255	Experimental trial	Little effect on microbial activity, DM intake, weight gain or DM FCR of pigs	(Geary et al., 1996)

*FCR- feed conversion ratios; †Diet dry matter concentrations (g/kg diet).

Table 4. Definitions of types of fermentation.

Type of fermentation	Definition	Source
Spontaneous	Fermentation through the action of indigenous microflora present in the feed	(Brooks, 2008)
Backslopping	A proportion of a previous fermentation is retained as an inoculum for fresh feed	(Moran et al., 2006).
	Consecutive microbial re-inoculation with micro-organisms from the previous batch	(Häggman and Salovaara, 2008)
Inoculated	Fermentation resulting from inoculation of feed with selected lactic acid bacteria	(Brooks, 2008)
Controlled	Fermentation resulting from inoculation of feed with selected lactic acid bacteria under controlled environmental conditions (e.g. temperature)	(e.g. Beal et al., 2002)

Table 5. Economic analysis of fermented liquid feed for pigs (Nguyen Nhut Xuan Dung et al. 2005).

Parameter	DF	NFLF	AF	FLF
Feed cost, VND/kg	3528	3528	5202	3528
Total feed intake, kg	220	213	216	195
Live weight gain, kg	50.9	49.6	55.4	55.0
Feed cost/gain, VND*	15.222	15.182	20.239	12.477

*Vietnamese dong (currency), DF- dry feed, NFLF-non-fermented liquid feed, AF-acidified feed, FLF-fermented liquid feed.

more, Xuan Dung et al. (2005) (Table 5) has indicated that feeding FLF to growing pigs is associated with the lowest feed cost/gain ratios compared with DF, NFLF and AF for growing-finishing pigs in Vietnam.

EFFECTS OF FERMENTED FEED ON PERFORMANCE POULTRY

Research on the use of fermented moist feeds on the performance of chickens is limited. However, some studies have shown that wet feeding increases the feed intake and growth rate of chickens (Yalda and Forbes, 1995; Yasar and Forbes, 1999; Mai, 2007). Pre-soaking of broiler feeds for 12 and 24 h significantly increased dry matter digestibility and body weight gain in male broilers (25 - 40 days of age) compared with dry feed (Yalda and Forbes, 1996). Bacterial fermentation of barley and wheat whole meal flours with -glucan-degrading LAB has improved growth and early feed:gain ratio in broiler chickens (Skrede et al., 2003). A 10% inclusion of fermented fish waste silage in poultry feed increased egg

quality and production in Japanese quails (Zynudheen et al., 2008).

Early access to semi-moist diets for day- old chicks stimulates gastrointestinal (GI) development and prevents dehydration during transport from the hatchery (van den Brink and van Rhee, 2007) . Rapid GI tract development after hatch is essential for optimisation of digestive function and underpins efficient growth and development as well as a full expression of the genetic potential for production traits (Mitchell and Moreto, 2006; Mai, 2007). Furthermore, the moistening capacity of the crop of chicks during the first weeks of life is also believed to be a limiting factor for the optimal functioning of the gut when standard solid diets are fed (Mai, 2007). Yasar and Forbes (1999) attributed the beneficial effects of wet feeding to decreased viscosity of gut contents, greater development of the layer of villi in the digestive segments and reduced crypt cell proliferation in the crypts of the epithelium. However, more research is required to provide a better understanding of the contribution of fermented moist feeds in poultry nutrition.

CONCLUSION

A successful application of fermented liquid feeds in pig or moist feeds in chicken feeding systems depends on the ability to select the right balance of LAB, feed substrates and fermentation conditions capable of producing repeatable fermentation results. Meanwhile, the resistance of such feeds to enteropathogen contamination during short storage, and their capability to reduce pathogen colonisation in the gut of pigs and poultry, could have far-reaching implications for improved food and environmental safety in warm wet regions of the African continent.

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