Application of Liquid Fermented Feed in Swine Production (Postprint)

Authors: Guan Xiaofeng, Liu Zhiyun, Huang Jinxiu, Yang Feiyun, Liu Zuohua

Date: 2018-12-25T00:00:00+00:00

Abstract

Modern liquid fermented feed is a stable feed product formed by mixing food industry by-products and agricultural by-products or feed with water at a ratio of 1.0:1.5 to 1:4, followed by sufficient fermentation, with advantages including inhibition of pathogen proliferation, improved growth performance in livestock and poultry, enhanced gastrointestinal health, expanded feed sources, and reduced production costs. Since the European Union announced a comprehensive ban on antibiotic feed additives, extensive research has been conducted on the production and application technologies of safe and effective antibiotic-free feed; as an antibiotic-free feed, liquid fermented feed holds broad application prospects. This article provides a comprehensive review of the production processes, quality-influencing factors, and applications of liquid fermented feed in pig production, aiming to provide a reference for its promotion and application.

Full Text

Application of Fermented Liquid Feed in Pig Production

GUAN Xiaofeng[1], **LIU Zhiyun**[2,3], **HUANG Jinxiu**[2,3], **YANG Feiyun**[2,3], **LIU Zuohua**[2,3*]

[1]College of Animal Science, Southwest University, Chongqing 402460, China
[2]Chongqing Academy of Animal Science, Chongqing 402460, China
[3]Chongqing Key Laboratory of Pig Industry Sciences, Chongqing 402460, China

Abstract: In its modern sense, fermented liquid feed refers to a stable feed product obtained through thorough fermentation of a mixture containing food industry by-products, agricultural and sideline products, or conventional feed ingredients with water at ratios ranging from 1.0:1.5 to 1:4. This feed type offers multiple advantages, including inhibition of pathogen proliferation, improved growth performance in livestock and poultry, enhanced gastrointestinal health, expanded feed resource utilization, and reduced production costs. Since the European Union' s complete ban on antibiotic feed additives, extensive research has been conducted on safe and effective antibiotic-free feed production technologies. As an antibiotic-free feed option, fermented liquid feed demonstrates broad application prospects. This review summarizes the production processes, quality-influencing factors, and applications of fermented liquid feed in pig production, aiming to provide references for its broader promotion and implementation.

Keywords: liquid fermentation; fermentation quality; influencing factors; pigs; growth performance; gastrointestinal health

---

1 Production Technology and Quality of Fermented Liquid Feed

Liquid feed can be categorized into two types: unfermented and fermented. Unfermented liquid feed refers to ready-to-use mixtures of feed and water in specific proportions. Fermented liquid feed, by contrast, is produced by mixing fermentation substrates with water at ratios of 1.0:1.5 to 1:4, allowing microorganisms in the fermentation liquid to metabolize and degrade macromolecular substances such as polysaccharides, proteins, and fats into smaller molecules. This process decomposes or transforms anti-nutritional factors while generating beneficial metabolites including organic acids (primarily lactic acid), bacteriocins, and digestive enzymes, ultimately yielding a low-pH, stable product rich in probiotic substances that is more easily digested and absorbed by livestock and poultry [1-2].

1.1 Production of Fermented Liquid Feed

Multiple fermentation approaches exist for producing fermented liquid feed. Based on substrate composition, these can be divided into complete-diet liquid fermentation and partial-grain liquid fermentation. Complete-diet fermentation represents the simplest production method [3]; however, it can lead to irreversible losses of nutrients such as vitamins and amino acids (especially synthetic amino acids) [3-6]. Partial-grain fermentation involves fermenting only the grain component first, then mixing it with other ingredients to create a complete liquid diet [1]. Compared to complete-diet fermentation, this approach not only prevents nutrient loss but also achieves faster and more stable fermentation due to the lower buffering capacity of the simpler substrate composition. Consequently, partial-grain fermentation has become the more widely adopted method [6-8].

Fermentation methods can also be classified as natural fermentation or inoculated fermentation (directed or induced fermentation). Natural fermentation relies on indigenous microorganisms present in the substrate, offering operational simplicity [6,9]; however, it risks uncontrolled proliferation of contaminating bacteria such as Enterobacteriaceae, making the fermentation process unpredictable [10] and potentially generating biogenic amines and high concentrations of acetic acid that compromise feed palatability and quality [5-6]. Inoculated fermentation introduces specific probiotic strains to initiate rapid, directed fermentation [7,11]. Research indicates that low pH and high lactic acid concentration are crucial for inhibiting pathogenic bacteria like Enterobacteriaceae [1] and represent an effective strategy to prevent explosive pathogen growth when pH rises significantly after mixing fermented grains with other ingredients [8]. Therefore, selected fermentation strains should exhibit rapid proliferation, substantial lactic acid production, and quick pH reduction capabilities. Currently, *Lactobacillus plantarum* and *Pediococcus pentosaceus* are commonly used for pig liquid feed fermentation [1]. Additionally, depending on the substrate, yeast and bacillus species can be combined with lactic acid bacteria to achieve specific objectives such as increasing microbial protein content or degrading anti-nutritional factors [12].

From a process perspective, fermentation can be batch or continuous (backslopping). Continuous fermentation retains a proportion (20%-50% [13]) of fermented product in the tank, which is then mixed with fresh substrate and water for ongoing fermentation [11]. This approach ensures continuous production and high productivity [13] but risks contaminant bacteria becoming dominant and reducing feed quality [9]. Batch fermentation, conversely, does not retain fermented product between cycles. While this means each batch must be cleaned and reloaded—requiring more sophisticated equipment and complex operation [9,14]—it offers greater control and more stable quality, as any fermentation failure affects only one batch [4-5].

1.2 Quality Parameters and Influencing Factors

High-quality fermented liquid feed should have a pH below 4.5, lactic acid bacteria counts exceeding 10 CFU/mL, lactic acid concentration above 150 mmol/mL, and acetic acid and ethanol concentrations below 40.0 mmol/mL and 0.8 mmol/mL, respectively [15]. High lactic acid concentration lowers feed pH, enhances palatability, and inhibits pathogen proliferation [7]. Lactic acid concentrations above 7 mmol/mL can inhibit *Salmonella* growth, while levels above 100 mmol/mL suppress *E. coli* proliferation [16-18]. Excessive acetic acid and ethanol produce off-flavors that reduce palatability [5].

Microbial species and population represent a primary factor affecting feed quality [18]. When lactic acid bacteria dominate, rapid lactic acid production improves palatability and inhibits pathogens such as *E. coli* and *Salmonella* [1]. Yeast dominance presents a dual impact: on one hand, yeasts can adsorb intestinal pathogens to their surface, preventing colonization of the intestinal mucosa [19-20]; on the other hand, yeast proliferation consumes substantial carbohydrates, producing ethanol, acetic acid, and carbon dioxide [5,21] that negatively affect palatability and dry matter content. In practice, the latter effect predominates, necessitating yeast-suppressed fermentation. Weak acids such as formic, sorbic, and benzoic acid inhibit yeast growth without affecting lactic acid bacteria [22].

Fermentation time, temperature, pH, and oxygen content also influence quality, with time and temperature being most significant. Within certain ranges, increasing temperature and extending duration enhance lactic acid yield and accumulation, improving pathogen inhibition. However, fermentation exceeding 72 hours risks over-fermentation and excessive carbohydrate consumption [23]. For optimal results, fermentation temperature should not fall below 15°C [19]; temperatures above 20°C show minimal quality differences [19], while 30°C significantly increases lactic acid production [16]. The feed-to-water ratio primarily affects dry matter content rather than quality within conventional ranges. Excessively high ratios increase dry matter content, reduce fluidity, and cause feed to adhere to pipelines and spoil, while excessively low ratios decrease dry matter intake and impair growth performance. Typical ratios range from 1.0:1.5 to 1:4, with 1:2 or 1:3 commonly used for pig feed [14,18].

2 Applications in Pig Production

2.1 Application in Weaned Piglets

Fermented liquid feed is widely used in European countries, particularly for weaned piglets, with numerous studies confirming its benefits. Domestic applications also focus primarily on weaned piglets to alleviate weaning stress, stimulate feed intake, and reduce weight loss.

2.1.1 Effects on Growth Performance Multiple trials have confirmed that fermented liquid feed increases average daily feed intake (ADFI) and average daily gain (ADG) in weaned piglets. Compared to dry feed, piglets fed fermented grain liquid feed [24] or complete-diet fermented liquid feed [25] showed ADFI improvements of 22.63% and 1.96%, and ADG improvements of 13.50% and 11.68%, respectively. The high lactic acid content provides an acidic aroma that stimulates intake, while the physical similarity to sow' s milk and simultaneous provision of nutrients and water prevent dehydration and reduce time needed to learn drinker use [26]. Furthermore, piglets consuming fermented liquid feed with 14.5%-25.5% dry matter content reduce non-feed water intake, maximizing dry matter consumption [27].

While effects on ADFI and ADG are consistent, feed conversion ratio (FCR) results vary. Chen et al. [28] reported that weaned piglets fed fermented liquid feed showed improved digestibility of crude protein (3.66%), calcium (3.85%), and total phosphorus (15.53%), with a 3.40% reduction in feed-to-gain ratio. Li [29] found FCR improvements of 8.68% and 10.90% compared to pelleted and mash feeds, respectively. Conversely, Li et al. [24] observed a 7.65% increase in feed-to-gain ratio with fermented liquid feed versus dry feed. The generally accepted mechanism involves probiotics degrading macromolecules into absorbable small molecules, reducing anti-nutritional factors, and producing beneficial metabolites that enhance nutrient utilization [30]. However, improved ADFI and ADG may paradoxically increase FCR due to feed wastage related to individual feeding space, feeding behavior, and trough design [27].

2.1.2 Effects on Gastrointestinal Health Fermented liquid feed improves gastrointestinal health and reduces diarrhea incidence in weaned piglets. Li [29] reported diarrhea rate reductions of 53.89% and 3.36% compared to mash and pelleted feeds, respectively. Li et al. [25] observed a 54.88% reduction in diarrhea for piglets fed fermented liquid feed versus dry feed. This effect results from multiple mechanisms.

First, fermented liquid feed addresses the post-weaning challenge of insufficient gastric acid secretion and elevated stomach pH, thereby enhancing pepsin hydrolytic activity, delaying gastric emptying, improving protein digestibility, and reducing diarrhea caused by protein malabsorption [13,31-32].

Second, it mitigates weaning stress-induced damage to intestinal villus structure and improves mucosal morphology. Scholten et al. [33] found that piglets fed fermented grain liquid feed showed 25.44% greater villus height and 36.36% higher villus length-to-crypt depth ratios compared to non-fermented liquid feed. This benefit stems not only from reduced viscosity causing less intestinal wall damage but also from easier acquisition of comprehensive, balanced nutrients. Additionally, increased volatile fatty acid concentrations (particularly butyrate) in the cecum promote intestinal cell growth, proliferation, and maintenance of mucosal integrity [30,34-35].

Finally, fermented liquid feed modulates gastrointestinal microbiota composition and balance, reducing disease incidence. Studies show significantly increased lactic acid bacteria populations in the stomach and small intestine [3,13], higher lactobacilli-to-*E. coli* ratios in the hindgut [8], and reduced fecal *E. coli* with increased lactobacilli [24] in piglets fed fermented liquid feed. As previously noted, the low pH enhances the stomach’ s natural barrier function, preventing pathogen passage to intestinal colonization sites [36]. Inoculated probiotics enter the digestive tract with feed, producing beneficial metabolites (lactic acid, bacteriocins, neurotransmitters, volatile fatty acids) that exert antimicrobial, antioxidant, and immunomodulatory effects [30,37]. They also positively regulate microbiota structure through pH reduction, oxygen consumption [20,30,38], and competition with pathogens for nutrients and colonization sites [30,39], thereby reducing pathogen loads and gastrointestinal disease incidence.

2.2 Application in Growing-Finishing Pigs

The effects of fermented liquid feed are less pronounced in growing-finishing pigs than in piglets, and the lack of supporting feeding systems has resulted in limited domestic research. In European countries, large-scale finishing farms commonly use inexpensive raw materials to produce fermented liquid feed, reducing production costs and improving profitability.

2.2.1 Effects on Growth Performance Results on growth performance in growing-finishing pigs are inconsistent. Jsenen et al. [19] reported 4.4% and 6.9% improvements in ADG and feed efficiency, respectively, with naturally fermented liquid feed. Chen et al. [40] found that inoculated lactic acid bacteria-fermented liquid feed increased ADG by 34.03% and 16.86% compared to dry and non-fermented liquid feeds, while reducing feed-to-gain ratio by 15.84% and 19.83%, respectively. Conversely, Canibe et al. [3] observed no significant effects on performance with 4-day naturally fermented liquid feed versus non-fermented liquid or pelleted feeds. These discrepancies likely relate to inconsistent fermentation direction and degree. Properly fermented feed can improve ileal apparent digestibility of crude protein, crude fiber, neutral detergent fiber, and fecal total tract digestibility of crude protein [41-42], whereas over-fermentation consumes substantial carbohydrates, reducing dry matter content and generating undesirable byproducts like acetic acid and ethanol that compromise quality [23]. Additionally, improper feed-to-water ratios adversely affect both dry matter content and palatability.

2.2.2 Effects on Carcass Quality While fermented liquid feed shows less pronounced effects on growth performance and gastrointestinal health in finishing pigs, it significantly influences carcass quality [42]. Feeding fermented liquid feed to uncastrated boars shifts tryptophan metabolism from skatole to indole in the hindgut, reducing skatole concentrations in longissimus dorsi muscle and subcutaneous fat, thereby decreasing boar taint [43]. Li et al. [44] reported that feeding a mixture of corn, soybean meal, wheat bran, cottonseed meal, and wheat shorts fermented with *Bacillus subtilis*, *Lactobacillus*, and *Saccharomyces cerevisiae* improved meat quality in finishing pigs, increasing redness value (a*), tenderness, intramuscular fat content, and flavor compounds while reducing drip loss. These improvements likely relate to fermentation-induced changes in flavor amino acid and small peptide composition.

2.2.3 Effects on Production Costs Unlike piglets, growing-finishing pigs have relatively mature physiological systems and show less pronounced responses to fermented liquid feed, but the approach offers unique cost advantages. Fermented liquid feed can incorporate substantial amounts of food processing byproducts and other agricultural products, expanding feed resources and improving cost-effectiveness. Research indicates that fermented liquid feed improves total tract apparent digestibility of dry matter [45] and reduces feed protein waste and costs by 6% [46]. The fermentation process increases crude protein, small peptide, and amino acid content while generating abundant enzymes [30] and liberating more phosphorus from feed ingredients, thereby improving utilization efficiency of protein and available phosphorus [9,31,43,47]. This reduces the need for supplemental phosphorus, protein, and amino acids, lowers feed cost per unit weight gain, and decreases excretion of phosphorus, sulfur, nitrogen, and odorous gases, improving health for both stockpersons and pigs while reducing medication costs.

When combined with appropriate feeding systems, fermented liquid feed reduces labor costs and enables precise delivery (accuracy up to 99.8% [32]), minimizing feed waste. Additionally, feeding fermented liquid feed during cold seasons eliminates the energy expenditure required to warm solid feed from 8°C to 38°C (1.44 MJ per pig per day [46]), preventing cold stress-related diseases and improving production efficiency.

2.3 Application in Sows

Fermented liquid feed is widely used for sows in European countries, with over 30% of Danish sows receiving it. Domestic applications remain relatively limited, primarily for maintaining body condition and improving reproductive performance.

2.3.1 Effects on Sow Performance Fermented liquid feed increases sow feed intake, maintains body condition, and reduces culling rates. Hong et al. [48] reported that sows fed naturally fermented liquid feed during lactation experienced 140.24% less body weight loss compared to dry-fed sows. John [49] found that fermented liquid feed increased average daily feed intake by 5.2% and annual piglets born by 12.0% while reducing piglet mortality by 13.8%. Since lactating sows prioritize nutrient utilization for milk production, inadequate energy intake forces mobilization of body reserves, causing severe weight loss. The physical properties of fermented liquid feed—good palatability, large volume, and satiety-inducing characteristics [31]—stimulate intake, help gestating sows obtain adequate water, reduce reproductive disorders and constipation, maintain stomach volume, and enable postpartum sows to rapidly restore feed intake for greater energy reserves and enhanced milk production. Additionally, fermented liquid feed increases immunoglobulin activity in colostrum and enhances mitogenic activity of lymphocytes and intestinal cells [50], improving passive immunity in newborn piglets.

2.3.2 Effects on Gastrointestinal Health of Sows and Offspring Newborn piglets have sterile intestines that acquire microbiota primarily through maternal and environmental contact [37,51]. *E. coli* in sows proliferates massively before farrowing due to stress, exposing piglets to high infection risk from birth. Fermented liquid feed effectively mitigates this issue. Demecková et al. [50] found that sows fed fermented liquid feed showed significantly reduced fecal *E. coli* and increased lactobacilli, while their offspring exhibited 5.5% higher lactobacilli and 7.3% lower *E. coli* in feces. Thus, fermented liquid feed creates a favorable environment for establishment and balance of neonatal microbiota by reducing pathogen loads in both sows and piglets. Furthermore, research demonstrates vertical transmission of feed-borne probiotics from sows to offspring, which is crucial for developing piglets' immune systems and future gastrointestinal physiology [52-53].

3 Summary and Outlook

Fermented liquid feed offers advantages in improving pig growth performance, gastrointestinal health, feed digestibility, resource utilization, and cost reduction. However, these benefits depend on rational diet formulation, mature fermentation technology, and complete production and feeding systems. Current limitations in China—including immature fermentation technology, unstable product quality, lack of supporting feeding systems, and high initial investment—restrict widespread adoption. While domestic and international research continues to optimize fermentation processes, practical applications require adjustments to feed formulas and feeding modes based on specific conditions to maximize advantages across different animal categories and production stages. The absence of integrated feeding systems creates a disconnect between production and delivery, increasing spoilage risk and labor costs. Therefore, development and promotion of compatible feeding systems are essential. As fermentation technology matures and production/feeding systems become standardized, fermented liquid feed will likely gain broader acceptance among producers, offering extensive application prospects.

References

[1] MISSOTTEN J A M, MICHIELS J, OVYN A, et al. Fermented liquid feed for pigs[J]. Archives of Animal Nutrition, 2010, 64(6): 437-466.

[2] 黄春喜, 刘晓慧, 张立彬, 等. 发酵液体饲料的生产及其在断奶仔猪上的应用 [J]. 饲料工业, 2014(增刊 1): 1-3.

[3] CANIBE N, JENSEN B B. Fermented and nonfermented liquid feed to growing pigs: effect on aspects of gastrointestinal ecology and growth performance[J]. Journal of Animal Science, 2003, 81(8): 2019-2031.

[4] BROOKS P H. Liquid feeding as a means to promote pig health[C]//MURPHY J M, LANGC F M D. 3rd London swine conference: maintaining your competitive edge. London: [s.n.], 2003: 83-103.

[5] BROOKS P H, BEAL J D, NIVEN S, et al. Liquid feeding of pigs. . Potential for improving pig health and food safety[J]. Animal Science Papers and Reports, 2003, 21(Suppl 1): 23-39.

[6] NIVEN S J, BEAL J D, BROOKS P H. The effect of controlled fermentation on the fate of synthetic lysine in liquid diets for pigs[J]. Animal Feed Science and Technology, 2006, 129(3/4): 304-315.

[7] CANIBE N, JENSEN B B. Fermented liquid feed: microbial and nutritional aspects and impact on enteric diseases in pigs[J]. Animal Feed Science and Technology, 2012, 173(1/2): 17-40.

[8] MORAN C A, SCHOLTEN R H J, TRICARICO J M, et al. Fermentation of wheat: effects of backslopping different proportions of pre-fermented wheat on

the microbial and chemical composition[J]. Archives of Animal Nutrition, 2006, 60(2): 158-169.

[9] BROOKS P H. Fermented liquid feed for pigs[Z]. CAB Review: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2008.

[10] BEAL J D, NIVEN S J, BROOKS P H, et al. Variation in short chain fatty acid and ethanol concentration resulting from the natural fermentation of wheat and barley for inclusion in liquid diets for pigs[J]. Journal of the Science of Food and Agriculture, 2005, 85(3): 433-440.

[11] NOUT M J R, ROMBOUTS F M, HAVELAAR A. Effect of accelerated natural lactic fermentation of infant food ingredients on some pathogenic microorganisms[J]. International Journal of Food Microbiology, 1989, 8(4): 351-361.

[12] 赵倩明, 占今舜. 发酵液体饲料常用菌种在养猪产业的应用 [J]. 猪业科学, 2017, 34(1): 92-93.

[13] MISSOTTEN J A, MICHIELS J, DEGROOTE J, et al. Fermented liquid feed for pigs: an ancient technique for the future[J]. Journal of Animal Science and Biotechnology, 2016, 6(1): 4.

[14] PLUMED-FERRER C, VON WRIGHT A. Fermented pig liquid feed: nutritional, safety and regulatory aspects[J]. Journal of Applied Microbiology, 2009, 106(2): 351-368.

[15] VAN WINSEN R L, URLINGS B A P, LIPMAN L J A, et al. Effect of fermented feed on the microbial population of gastrointestinal tracts of pigs[J]. Applied Environmental Microbiology, 2001, 67(7): 3071-3076.

[16] BEAL J D, NIVEN S J, CAMPBELL A, et al. The effect of temperature on the growth and persistence of Salmonella in fermented liquid feed[J]. International Journal of Microbiology, 2002, 79(1/2): 99-104.

[17] MORAN C A, BEAL J D, CAMPBELL A, et al. The survival of potentially pathogenic E. coli in fermented liquid feed[M]//LINDBERG I J E, OGLE B. Digestive Physiology in Pigs. Proceedings of the 8th Symposium. Wallingford: CABI Publishing, 2001: 351-353.

[18] NIBA A T, BEAL J D, KUDI A C, et al. Potential of bacterial fermentation as a biosafe method of improving feeds for pigs and poultry[J]. African Journal of Biotechnology, 2009, 8(9): 1758-1767.

[19] JENSEN B B, MIKKELSEN L L. Feeding liquid diets to pigs[M]//WISEMAN J. Recent developments in pig nutrition. Nottingham: Nottingham University Press, 1998: 107-126.

[20] AREVALO-VILLENA M, BRIONES-PEREZA A, CORBO M R, et al. Biotechnological application of Yeasts in food science: starter cultures, probiotics and enzyme production[J]. Journal of Applied Microbiology, 2017, 123(6): 1360-1372.

[21] MORAN C A. Developments and benefits of liquid feeding through fermentation for the post-weaned pig[D]. Ph.D. Thesis. Plymouth: University of Plymouth, 2001.

[22] PLUMED-FERRER C, VON WRIGHT A. Antimicrobial activity of weak acids in liquid feed fermentations, and its effects on Yeasts and Lactic acid bacteria[J]. Journal of the Science of Food and Agriculture, 2011, 91(6): 1032-1040.

[23] SCHOLTEN R. Fermentation of liquid diets for pigs[D]. Ph.D. Thesis. Wageningen: Wageningen Universiteit, 2001.

[24] 李永明, 徐子伟, 李芳, 等. 发酵谷物液体饲料对超早期断奶仔猪生长性能和肠道微生物菌群多样性的影响 [J]. 动物营养学报, 2010, 22(6): 1650-1657.

[25] 李洁, 张孟阳, 郭宏, 等. 仔猪液体发酵饲料工艺的研制 [J]. 饲料工业, 2017, 38(15): 15-21.

[26] BARBER J. The rationalisation of drinking water supplies in pig housing[D]. Ph.D. Thesis. Plymouth: Polytechnic South West, 1992.

[27] RUSSELL P J, GEARY T M, BROOKS P H, et al. Performance, water use and effluent output of weaner pigs fed ad libitum with either dry pellets or liquid feed and the role of microbial activity in the liquid feed[J]. Journal of the Science of Food and Agriculture, 2015, 72(1): 8-16.

[28] 陈鲜鑫, 王金全, 刘震坤, 等. 玉米乳杆菌发酵液体饲料对断奶仔猪生产性能、养分消化率（全收粪法）和血清生化免疫指标的影响 [J]. 饲料研究, 2017(5): 5-9, 39.

[29] 李小燕. 液体发酵饲料的研制及其对断奶仔猪生长性能的影响 [D]. 硕士学位论文. 合肥: 安徽大学, 2013.

[30] WANG C, SHI C Y, ZHANG Y, et al. Microbiota in fermented feed and swine gut[J]. Applied Microbiology and Biotechnology, 2018, 102(7): 2941-2948.

[31] LYBERG K, LUNDH T, PEDERSEN C, et al. Influence of soaking, fermentation and phytase supplementation on nutrient digestibility in pigs offered a grower diet based on wheat and barley[J]. Animal Science, 2006, 82(6): 853-858.

[32] RADECKI S V, JUHL M R, MILLER E R. Fumaric and citric acids as feed additives in starter pig diets: effect on performance and nutrient balance[J]. Journal of Animal Science, 1988, 66(10): 2598-2605.

[33] SCHOLTEN R H J, VAN DER PEET-SCHWERING C M C, DEN HARTOG L A, et al. Fermented wheat in liquid diets: effects on gastrointestinal characteristics in weanling piglets[J]. Journal of Animal Science, 2002, 80(5): 1179-1186.

[34] TAJIMA K, OHMORI H, AMINOV R I, et al. Fermented liquid feed enhances bacterial diversity in piglet intestine[J]. Anaerobe, 2010, 16(1): 6-11.

[35] NIELSEN D S G, JENSEN B B, THEIL P K, et al. Effect of butyrate and fermentation products on epithelial integrity in a mucus-secreting human colon line[J]. Journal of Functional Foods, 2018, 40: 9-17.

[36] 夏耀耀, 任文凯, 黄瑞林, 等. 仔猪肠道微生物研究进展 [J]. 中国实验动物学报, 2017, 25(6): 681-688.

[37] SÁNCHEZ B, DELGADO S, BLANCO-MÍGUEZ A, et al. Probiotics, gut microbiota, and their influence on host health and disease[J]. Molecular Nutrition & Food Research, 2016, 61(1), doi:10.1002/mnfr.201600240.

[38] 麻名汉. 液体发酵饲料对断奶仔猪肠道健康的影响探究 [J]. 现代畜牧科技, 2017(6): 50.

[39] CASEY P G, CASEY G D, GARDINER G E, et al. Isolation and characterization of anti-Salmonella lactic acid bacteria from the porcine gastrointestinal tract[J]. Letters in Applied Microbiology, 2004, 39(5): 431-438.

[40] 陈鲜鑫, 王金全, 王春阳, 等. 乳酸菌发酵液体饲料对生长猪生长性能和粪中微生物区系的影响 [J]. 饲料工业, 2010, 31(4): 40-42.

[41] HONG T T T, LINDBERG J E. Effect of cooking and fermentation of a pig diet on gut environment and digestibility in growing pigs[J]. Livestock Science, 2007, 109(1/2/3): 135-137.

[42] DUNG N N X, MANH L H, OGLE B. Effects of fermented liquid feeds on performance, digestibility, nitrogen retention and plasma urea nitrogen (PUN) of growing-finishing pigs[J]. Livestock Research for Rural Development, 2005, 17(9): 102.

[43] JØRGENSEN H, SHOLLY D, PEDERSEN A Ø, et al. Fermentation of cereals-influence on digestibility of nutrients in growing pigs[J]. Livestock Science, 2010, 134(1/2/3): 56-58.

[44] 李敏, 武进, 张石蕊, 等. 微生物发酵饲料对育肥猪生长性能、胴体性能及肉质的影响 [J]. 湖南饲料, 2012(2): 16-21.

[45] 赵伟, PEDERSEN C, STEN H H. 液体发酵饲料对生长育肥猪的能量、干物质、蛋白质以及磷消化率的影响 [J]. 饲料与畜牧, 2015(11): 25-27.

[46] SCHONBAUER H. 发酵液态饲料: 从肠道健康入手改善猪群健康-稀料饲喂系统的发展历史及运用前景 [J]. 今日养猪业, 2016(5): 28-31.

[47] SHI C, ZHANG Y, YIN Y, et al. Amino acid and phosphorus digestibility of fermented corn-soybean meal mixed feed with Bacillus subtilis and Enterococcus faecium fed to pigs[J]. Journal of Animal Science, 2017, 95(9): 3996-4004.

[48] HONG J S, JIN S S, JUNG S W, et al. Evaluation of dry feeding and liquid feeding to lactating sows under high temperature environment[J]. Journal of Animal Science and Technology, 2016, 58: 36.

[49] JOHN G. The pipeline pig-feeding revolution[J]. The Pig Pen, 1998, 4: 1-8.

[50] DEMECKOVÁ V, KELLY D, COUTTS A G P, et al. The effect of fermented liquid feeding on the faecal microbiology and colostrum quality of farrowing sows[J]. International Journal of Food Microbiology, 2002, 79(1/2): 85-97.

[51] KONSTANTINOV S R, AWATI A A, WILLIAMS B A, et al. Post-natal development of the porcine microbiota composition and activities[J]. Environmental Microbiology, 2010, 8(7): 1191-1199.

[52] DEMECKOVA V, TSOURGIANNIS C A, BROOKS P H. Beneficial changes of Lactobacilli, Coliforms and E.coli numbers in the feces of farrowing primiparous sows, achieved by fermented liquid feed, positively affect subsequent neonatal colonization[C]//Proceedings of the 9th International Symposium on Digestive Physiology in Pigs. Edmonton, AB: University of Alberta, 2003: 84-86.

[53] TARAS D, VAHJEN W, SIMON O. Probiotics in pigs-modulation of their intestinal distribution and of their impact on health and performance[J]. Livestock Science, 2007, 108(1/2/3): 229-231.

Note: Figure translations are in progress. See original paper for figures.