

## Post-print: Nutritional Value Evaluation of Vinegar Residue and Fermented Vinegar Residue in Laying Hens

**Authors:** Yang Yaoxiang, Dong Xiaofang, Tong Jianming

**Date:** 2018-12-24T00:00:00+00:00

### Abstract

This study aimed to compare and evaluate the nutritional value of vinegar residue and fermented vinegar residue in laying hens. Fifty-six 47-week-old Hy-Line Brown laying hens were randomly allocated into 7 groups with 8 replicates per group and 1 hen per replicate. Group 1 (control) was fed a corn-soybean meal basal diet, groups 2-4 were fed experimental diets in which vinegar residue substituted 10%, 15%, and 20% of the basal diet, respectively, and groups 5-7 were fed experimental diets in which fermented vinegar residue substituted 10%, 15%, and 20% of the basal diet, respectively. Following a 5-day preliminary feeding period, a 6-day metabolic trial was conducted. The results demonstrated that the gross energy and apparent metabolic rate of dry matter in the diets decreased with increasing substitution levels of vinegar residue or fermented vinegar residue, with significant differences among groups ( $P < 0.05$ ). Compared with the control group, all substitution levels of vinegar residue or fermented vinegar residue significantly reduced the apparent metabolizable energy and apparent metabolic rate of crude protein ( $P < 0.05$ ), while significantly increasing the apparent metabolic rate of crude fiber ( $P < 0.05$ ). When the substitution method was employed to determine the available nutrient content of vinegar residue and fermented vinegar residue, no significant difference was found between them ( $P > 0.05$ ); however, fermented vinegar residue exhibited an improving trend in available nutrient content, suggesting that mixed-culture fermentation of vinegar residue could enhance its nutrient utilization in laying hens. When evaluating the nutritional value of vinegar residue and fermented vinegar residue in laying hens using the substitution method, a substitution level of 20% is recommended.

## Full Text

# Evaluation of Nutrient Value of Vinegar Residue and Fermented Vinegar Residue for Laying Hens

**YANG Yaoxiang, DONG Xiaofang, TONG Jianming**

*Institute of Animal Science, Chinese Academy of Agricultural Sciences, Beijing 100193, China*

**Received:** 2017-12-09

**Funding:** “Twelfth Five-Year” National Science and Technology Support Program (2013BAD10B04); Chinese Academy of Agricultural Sciences Agricultural Science and Technology Innovation Project (ASTIP-IAS08); National Egg Chicken Industry Technology System Special Fund (CARS-41-K16)

**Author information:** YANG Yaoxiang (1991–), male, from Liulin, Shanxi, Master, engaged in poultry nutrition and feed science research. E-mail: yyx1859@163.com. \*Corresponding author: DONG Xiaofang, associate professor, master’s supervisor, E-mail: xiaofangd1124@sina.com

## Abstract

This study aimed to compare and evaluate the nutritional value of vinegar residue (VR) and fermented vinegar residue (FVR) for laying hens. Fifty-six 47-week-old Hy-Line Brown laying hens were randomly allocated to 7 groups with 8 replicates per group and 1 hen per replicate. Hens in group 1 (control) were fed a corn-soybean meal basal diet, those in groups 2–4 were fed experimental diets with 10%, 15%, and 20% VR substitution for the basal diet, respectively, and those in groups 5–7 were fed experimental diets with 10%, 15%, and 20% FVR substitution, respectively. After a 5-day pre-feeding period, a 6-day metabolic trial was conducted. The results showed that the apparent metabolic rates of total energy and dry matter in diets decreased with increasing VR or FVR substitution ratios, with significant differences among all groups ( $P < 0.05$ ). Compared with the control group, different VR or FVR substitution ratios significantly reduced the apparent metabolic energy and crude protein apparent metabolic rate of diets ( $P < 0.05$ ), while significantly increasing the crude fiber apparent metabolic rate ( $P < 0.05$ ). Using the substitution method to determine the available nutrient contents of VR and FVR, no significant differences were found between them ( $P > 0.05$ ), but FVR showed an improving trend in available nutrient contents, indicating that mixed-strain fermentation of VR can improve its nutrient utilization in laying hens. When evaluating the nutritional value of VR and FVR for laying hens using the substitution method, a substitution ratio of 20% is recommended.

**Key words:** vinegar residue; fermented vinegar residue; laying hens; nutritional value

With the continuous development of the livestock industry, feed resource scarcity has become a major bottleneck restricting the stable and sustainable development of animal husbandry in China, making the exploitation and utilization of unconventional feed resources increasingly important. Vinegar residue is a solid waste obtained from the solid-state fermentation process of vinegar production using starchy raw materials as the main ingredient[1-2]. China is a major vinegar-producing country, with vinegar output reaching 4 million tons in 2015[3]. Based on the calculation that producing 1 ton of standard solid-state fermented secondary vinegar generates 0.8 tons of vinegar residue[4], fresh vinegar residue production in China reached 3.2 million tons in 2015. As a grain by-product, vinegar residue is an important unconventional feed raw material in China. Currently, only a small portion of vinegar residue is used in livestock and poultry diets with low utilization efficiency, while most of it remains underutilized, resulting in not only resource waste but also environmental pollution. Therefore, the development and utilization of vinegar residue are of great significance.

## 1.1 Materials

Vinegar residue was collected from Shanxi Donghu Vinegar Industry Co., Ltd. (black vinegar residue). Fermented vinegar residue was produced by solid-state fermentation of the black vinegar residue for 5 days using *Phanerochaete chrysosporium* ACCC30414, *Trichoderma koningii* CGMCC3.2878, *Aspergillus niger* ACCC30557, and *Aspergillus ficuum* NTG-234 according to the optimized process parameters of our laboratory[13]. The nutrient composition of vinegar residue and fermented vinegar residue is shown in Table 1 .

## 1.2 Experimental Design and Management

This experiment used the substitution method to determine the apparent metabolic rate and apparent metabolic energy of nutrients in vinegar residue and fermented vinegar residue. Fifty-six 47-week-old Hy-Line Brown laying hens with similar body weight and normal feed intake and egg production were randomly divided into 7 groups, with 8 replicates per group and 1 hen per replicate. Group 1 (control group) was fed a corn-soybean meal basal diet, groups 2-4 were fed experimental diets with 10%, 15%, and 20% substitution of the basal diet with vinegar residue, respectively, and groups 5-7 were fed experimental diets with 10%, 15%, and 20% substitution of the basal diet with fermented vinegar residue, respectively. The pre-test period lasted 5 days, and the formal test period lasted 6 days. At 19:00 on the last day of the pre-test period, feed was withdrawn, and the hens were immediately fed the corresponding experimental diets, and new excreta trays were installed to collect excreta.

The feeding trial was conducted at the Changping Base of the Institute of Animal Science, Chinese Academy of Agricultural Sciences. The experimental hens

were individually weighed at the beginning and end of the trial. The hens had free access to feed and water, with a lighting schedule of 16 h per day using natural light supplemented with artificial lighting. Feed was provided three times daily, with fresh feed weighed by replicate [120 g/(d·hen)], each replicate having one feed bucket marked with group and replicate numbers. Daily temperature and humidity in the hen house were recorded, and the health status of the hens was observed.

### 1.3 Experimental Diets

A corn-soybean meal basal diet was formulated according to the nutrient requirements for laying hens recommended by NRC (1994) to produce powdered compound feed. The composition and nutrient levels of the basal diet are shown in Table 2 .

**Table 2 Composition and nutrient levels of the basal diet (air-dry basis) %**

Item	Content
<b>Ingredients</b>	
Corn	
Soybean meal	
Soybean oil	
Limestone	
Wheat middlings	
CaHPO	
NaCl	
Choline chloride	
Met	
Vitamin premix <sup>1)</sup>	
Trace mineral premix <sup>2)</sup>	
<b>Total</b>	
<b>Nutrient levels<sup>3)</sup></b>	
GE (MJ/kg)	
ME (MJ/kg)	
CP	
EE	
Ash	
CF	
NDF	
ADF	

<sup>1)</sup> The vitamin premix provided the following per kg of the diet: VA 8,000 IU, VD 3,000 IU, VE 15 IU, VK 2 mg, VB 2 mg, VB 4 mg, VB 4 mg, VB 0.01 mg, calcium pantothenate 12 mg, nicotinic acid 40 mg, folic acid 1 mg, biotin

0.1 mg, choline 212.5 mg.

<sup>2)</sup> The trace mineral premix provided the following per kg of the diet: Mn (as manganese sulfate) 63.6 mg, Zn (as zinc sulfate) 69 mg, Fe (as ferrous sulfate) 30 mg, Cu (as copper sulfate) 6.25 mg, I (as potassium iodide) 0.4 mg, Se (as sodium selenite) 0.2 mg.

<sup>3)</sup> ME was a calculated value, and the others were measured values.

## 1.4 Sample Collection and Processing

The total excreta collection method was used to collect feces and urine. During the formal test period, excreta were collected by replicate twice daily at 11:00 and 19:00. During collection, chicken feathers, dander, and feed were removed from the excreta trays, and the excreta were scraped into self-sealing bags without loss and weighed. Ten milliliters of 10% hydrochloric acid was added per 100 g of excreta to prevent ammonia nitrogen loss[13]. After collection, the 6-day excreta samples were thoroughly mixed, dried to constant weight in an oven at 65°C, weighed and recorded after equilibrating at room temperature for 24 h, and stored for analysis.

### 1.5.1 Nutrient Composition of Diets and Feces

The contents of total energy, dry matter, crude protein, crude fat, crude ash, crude fiber, acid detergent fiber, and neutral detergent fiber in diets and feces of each group were determined. Total energy was determined according to ISO 9831:1998; dry matter according to GB/T 6435-2014; crude protein according to GB/T 6432-1994; crude fat according to GB/T 6433-2006; crude ash according to GB/T 6438-2007; crude fiber according to GB/T 6434-2006; acid detergent fiber according to NY/T 1459-2007; and neutral detergent fiber according to GB/T 20806-2006.

### 1.5.2 Apparent Metabolic Rate of Target Nutrients in Diets, Apparent Metabolic Energy, and Available Nutrient Contents of Vinegar Residue and Fermented Vinegar Residue[1]

The apparent metabolic rate of a nutrient in the diet was calculated using the total collection method according to the following formula:

Apparent metabolic rate of a nutrient (%) = [(nutrient intake - nutrient in feces) / nutrient intake] × 100.

The apparent metabolic rate of a nutrient in vinegar residue or fermented vinegar residue was calculated using the substitution method according to the following formula:

$$D = [(A - B) / F] + B.$$

Where: D is the apparent metabolic rate of a nutrient in vinegar residue or fermented vinegar residue (%); A is the apparent metabolic rate of a nutrient in

the experimental diet (%); B is the apparent metabolic rate of a nutrient in the basal diet (%); F is the proportion of the same nutrient from vinegar residue or fermented vinegar residue in the experimental diet (%).

The apparent metabolic energy of diets, vinegar residue, and fermented vinegar residue was calculated as follows:

Apparent metabolic energy = total energy × apparent metabolic rate of energy.

The available nutrient content in vinegar residue and fermented vinegar residue was calculated as follows:

Available nutrient content in vinegar residue or fermented vinegar residue = nutrient content in vinegar residue or fermented vinegar residue × apparent metabolic rate of the nutrient in vinegar residue or fermented vinegar residue.

## 1.6 Statistical Analysis

Data were analyzed using SAS 9.3 statistical software for one-way ANOVA and independent samples t-test, with  $P < 0.05$  as the criterion for significant difference.

## 2.1 Nutrient Composition of Diets and Feces

The nutrient composition of diets and feces is shown in Tables 3 and 4.

**Table 3 Nutrient composition of diets (air-dry basis)**

Item	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
GE							
(MJ/kg)							
DM							
CP							
EE							
Ash							
CF							
NDF							
ADF							

**Table 4 Nutrient composition of feces (air-dry basis)**

Item	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
GE	13.25±0.43	14.45±0.51	15.43±0.34	15.23±0.40	15.00±0.34	15.69±0.20	16.13±0.17
(MJ/kg)							
DM	95.37±0.87	94.83±0.19	95.03±0.19	95.04±0.31	94.86±0.35	96.94±0.23	96.78±0.28

Item	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
CP	36.77±1.50	29.67±1.05	27.59±0.87	26.33±1.25	31.38±1.43	29.95±1.09	28.35±0.53
EE	3.18±0.38	2.44±0.38	1.51±0.17	1.76±0.18	2.09±0.36	2.74±0.38	2.46±0.24
Ash	24.44±2.12	19.58±1.95	16.31±1.56	17.40±2.13	18.11±1.24	17.24±0.99	15.74±0.99
CF	20.54±2.60	14.23±1.40	14.56±0.90	15.66±0.60	12.58±1.10	13.70±0.84	14.73±2.17
NDF	38.86±4.55	43.76±1.68	49.66±1.78	48.39±2.55	43.76±2.04	48.26±2.85	49.46±2.45
ADF	13.35±2.43	13.96±1.10	19.35±0.94	19.09±3.12	16.87±0.98	13.02±2.03	16.08±1.81

## 2.2 Effects of Different Vinegar Residue and Fermented Vinegar Residue Substitution Ratios on Dietary Nutrient Apparent Metabolic Rates and Apparent Metabolic Energy

As shown in Table 5, the apparent metabolic rates of total energy and dry matter in diets decreased with increasing vinegar residue substitution ratio, with significant differences among all groups ( $P < 0.05$ ). Compared with group 1, the apparent metabolic energy of diets in groups 2, 3, and 4 was significantly reduced ( $P < 0.05$ ); compared with group 2, the apparent metabolic energy of diets in groups 3 and 4 was significantly reduced ( $P < 0.05$ ). Compared with group 1, the apparent metabolic rates of crude protein and neutral detergent fiber in groups 2, 3, and 4 were significantly reduced ( $P < 0.05$ ); compared with groups 2 and 3, the apparent metabolic rates of crude protein and neutral detergent fiber in group 4 were significantly reduced ( $P < 0.05$ ). Compared with group 1, the apparent metabolic rate of crude fiber in groups 2, 3, and 4 was significantly increased ( $P < 0.05$ ); compared with group 2, the apparent metabolic rate of crude fiber in groups 3 and 4 was significantly increased ( $P < 0.05$ ). The apparent metabolic rates of crude fat and crude ash differed significantly among groups ( $P < 0.05$ ), but did not change regularly with vinegar residue substitution ratio. There was no significant difference in apparent metabolic rate of acid detergent fiber among groups ( $P > 0.05$ ).

As shown in Table 6, the apparent metabolic rates of total energy and dry matter and apparent metabolic energy of diets decreased with increasing fermented vinegar residue substitution ratio, with significant differences among all groups ( $P < 0.05$ ). Compared with group 1, the apparent metabolic rate of crude protein in groups 5, 6, and 7 was significantly reduced ( $P < 0.05$ ); the apparent metabolic rate of crude protein in group 7 was significantly lower than that in group 5 ( $P < 0.05$ ). Compared with groups 1 and 5, the apparent metabolic rates of crude fat and neutral detergent fiber in groups 6 and 7 were significantly reduced ( $P < 0.05$ ). Compared with group 1, the apparent metabolic rate of crude fiber in groups 5, 6, and 7 was significantly increased ( $P < 0.05$ ); the apparent metabolic rate of crude fiber in group 7 was significantly higher than that in groups 5 and 6 ( $P < 0.05$ ). There was no significant difference in apparent metabolic rates of crude ash and acid detergent fiber among groups ( $P > 0.05$ ).

**Table 5 Effects of different vinegar residue substitution ratios on nutrient apparent metabolism rate and apparent metabolism energy of diets (n=8)**

Item	Group 1	Group 2	Group 3	Group 4	P-value
GE (MJ/kg)	80.98±2.11a	71.58±1.45b	67.19±0.75c	63.80±1.34d	<0.0001
ME (MJ/kg)	12.49±0.32a	10.69±0.22b	10.25±0.11c	10.16±0.21c	<0.0001
DM	76.27±3.29a	69.06±1.79b	65.74±1.13c	60.04±2.02d	<0.0001
CP	50.12±6.60a	43.80±4.21b	43.53±2.74b	36.53±3.87c	<0.0001
EE	81.84±3.76b	78.22±4.05c	85.99±1.58a	80.33±2.65bc	
Ash	50.69±10.49ab	51.54±6.42a	57.93±5.18a	42.47±9.82b	
CF	11.38±8.73c	16.17±7.36b	24.09±4.63a	25.88±2.80a	
NDF	23.92±10.63a	14.76±4.32b	13.07±3.00b	6.03±5.31c	<0.0001
ADF	12.60±10.36	7.47±3.67	5.51±2.93	4.45±3.95	

In the same row, values with no letter or the same letter superscripts mean no significant difference ( $P > 0.05$ ), while with different small letter superscripts mean significant difference ( $P < 0.05$ ). The same as below.

**Table 6 Effects of different fermented vinegar residue substitution ratios on nutrient apparent metabolism rate and apparent metabolism energy of diets (n=8)**

Item	Group 1	Group 5	Group 6	Group 7	P-value
GE (MJ/kg)	80.98±2.11a	71.61±1.17b	67.63±1.00c	63.33±1.18d	<0.0001
ME (MJ/kg)	12.49±0.32a	11.14±0.18b	10.75±0.16c	10.23±0.19d	<0.0001
DM	76.27±3.29a	69.00±0.95b	64.79±1.00c	60.74±1.65d	<0.0001
CP	50.12±6.60a	44.15±3.13b	40.23±2.38bc	37.03±2.88c	<0.0001
EE	81.84±3.76a	83.38±2.97a	76.34±3.61b	76.14±3.07b	<0.0001
Ash	50.69±10.49	52.87±3.00	50.83±3.21	44.84±5.47	
CF	11.38±8.73c	21.90±3.89b	22.31±5.80b	28.56±6.64a	
NDF	23.92±10.63a	21.40±5.25a	9.58±6.30b	13.02±4.86b	
ADF	12.60±10.36	11.73±5.03	4.07±2.36	6.85±4.94	

### 2.3 Comparison of Available Nutrient Contents Between Vinegar Residue and Fermented Vinegar Residue

As shown in Table 7, there was no significant difference in available nutrient contents between vinegar residue and fermented vinegar residue ( $P > 0.05$ ), but

fermented vinegar residue showed an improving trend. Compared with vinegar residue, fermented vinegar residue showed increases of 6.16% in apparent metabolic energy, 21.61% in available dry matter, 56.52% in available protein, 18.45% in available crude fat, 10.97% in available crude ash, 2.06% in available crude fiber, 49.04% in available neutral detergent fiber, and 115.93% in available acid detergent fiber.

**Table 7 The contents of available nutrients of vinegar residue and fermented vinegar residue**

Item	Vinegar residue (n=8)	Fermented vinegar residue (n=8)	P-value
ME (MJ/kg)	1.46±0.75	1.55±0.36	
DM	5.23±2.12	6.36±3.77	
CP	0.92±0.29	1.44±0.84	
EE	2.33±1.65	2.76±1.58	
Ash	3.19±1.98	3.54±1.43	
CF	14.59±3.83	14.89±4.53	
NDF	4.71±4.00	7.02±3.52	
ADF	2.26±1.42	4.88±2.97	

### 3 Discussion

The substitution method is a classical approach for determining the nutrient utilization rate of individual feedstuffs. This experiment employed this method to determine the available nutrient contents of vinegar residue and fermented vinegar residue, which assumes that the digestibility of nutrients in the basal diet is additive—that is, the nutrient digestibility of the basal diet and vinegar residue or fermented vinegar residue remains constant in the experimental diets. This study used vinegar residue or fermented vinegar residue to replace 10%, 15%, or 20% of the basal diet to determine dietary nutrient apparent metabolic rates and apparent metabolic energy. The results demonstrated that as the substitution ratio of vinegar residue or fermented vinegar residue in diets increased, the apparent metabolic rates of total energy, dry matter, and crude protein, as well as apparent metabolic energy, decreased. This may be attributed to the increased crude fiber content in diets with higher substitution ratios, which reduced digesta retention time in the gastrointestinal tract and accelerated passage rate, preventing complete digestion and absorption of dietary nutrients and thereby reducing nutrient utilization[14].

China's vinegar production continues to increase annually, leading to corresponding increases in vinegar residue output. Vinegar residue is highly acidic, decomposes slowly, and is difficult to manage, potentially becoming a significant environmental pollutant if not developed and utilized promptly and rationally[15]. Due to its high crude fiber and low crude protein content, the direct use of vinegar residue as a feed ingredient provides limited nutritional

value for livestock and poultry, greatly restricting its application in animal diets. However, vinegar residue contains substantial amounts of underutilized components such as crude fiber and non-protein nitrogen, making it possible to convert waste into valuable resources through appropriate development. Microbial fermentation currently represents the primary technical approach for developing unconventional feed resources. Previous research has demonstrated that *Phanerochaete chrysosporium* is the most extensively studied white-rot fungus with strong lignin-degrading capabilities[16], secreting lignin peroxidase to degrade lignin[17]. *Trichoderma koningii* can decompose cellulose and produce cellulase using high-cellulose materials[18-19]. *Aspergillus niger* grows rapidly with a short enzyme production cycle, is a safe strain that can produce cellulase using high crude fiber materials without generating mycotoxins during fermentation[20-22]. *Aspergillus ficuum* is the primary strain for phytase production and is used in commercial phytase manufacturing. Wang Zhihong[23] reported that *Aspergillus ficuum* can grow in vinegar residue without added nitrogen or carbon sources and produce phytase. Cui Yaoming[12] found that after optimal fermentation of vinegar residue with these four strains, carboxymethyl cellulase and xylanase activities increased by 418.99% and 507.45%, respectively, compared with single-strain fermentation. This experiment evaluated the nutritional value of vinegar residue and fermented vinegar residue for laying hens using the substitution method. The fermented vinegar residue used was produced through mixed fermentation of vinegar residue with *Phanerochaete chrysosporium*, *Trichoderma koningii*, *Aspergillus niger*, and *Aspergillus ficuum*. After microbial fermentation, the crude protein content of vinegar residue increased by 14.24%, starch content increased by 46.75%, crude fiber content decreased by 7.97%, cellulose content decreased by 6.12%, and hemicellulose content decreased by 68.06%. The results indicated that although no significant differences were observed in available nutrient contents between fermented vinegar residue and vinegar residue, all values numerically improved, demonstrating that mixed-strain fermentation can enhance nutrient utilization of vinegar residue in laying hens.

## 4 Conclusion

When evaluating the nutritional value of vinegar residue and fermented vinegar residue for laying hens using the substitution method, a substitution ratio of 20% is recommended.

## References

- [1] SONG Z T, DONG X F, TONG J M, et al. In sacco evaluation of ruminal degradability of waste vinegar residue feedstuff ruminants[J]. Animal Production Science, 2013, 53(4): 292-298.
- [2] WANG Z H, DONG X F, ZHANG G Q, et al. Waste vinegar residue as substrate for phytase production[J]. Waste Management & Research, 2011, 29(12): 1262-1270.

- [3] 田波, 赵顺华, 张俊红, 等. 醋糟资源化利用研究进展 [J]. 中国酿造, 2017, 36(3): 1-4.
- [4] 王芳, 上官明军, 张变英, 等. 山西省醋糟资源现状及其在动物生产中的应用 [J]. 畜禽业, 2014(10): 44-46.
- [5] SONG Z T, DONG X F, TONG J M, et al. Effects of waste vinegar residue on nutrient digestibility and nitrogen balance in laying hens[J]. Livestock Science, 2012, 150(1/2/3): 67-73.
- [6] SONG Z T, DONG X F, TONG J M, et al. Effects of inclusion of waste vinegar residue in the laying chyme characteristics gut microflora[J]. Livestock Science, 2014, 167: 292-296.
- [7] 花卫华, 单昊书, 徐志伟, 等. 醋糟对湖羊羔羊育肥效果的研究 [J]. 安徽农业科学, 2008, 36(32): 14105, 14112.
- [8] 马希景, 李中利. 醋糟饲喂肉兔的效果试验 [J]. 中国养兔杂志, 2003(4): 14-15.
- [9] 曹亮. 日粮中不同醋糟添加水平对獭兔的影响研究 [D]. 硕士学位论文. 太谷: 山西农业大学, 2014: 8-21.
- [10] 陈永霞, 单昊书, 王寿宽, 等. 干醋糟饲喂肉猪试验 [J]. 上海畜牧兽医通讯, 2008(1): 35.
- [11] 杨庆文, 彭晓光, 杨林娥, 等. 醋糟的开发与利用 [J]. 山西农业科学, 2009, 37(2): 44-46.
- [12] 崔耀明. 山西老陈醋醋糟混菌发酵菌种筛选及其发酵条件优化 [D]. 硕士学位论文. 北京: 中国农业科学院, 2015.
- [13] 周安国, 陈代文. 动物营养学 [M]. 3 版. 北京: 中国农业出版社, 2011: 148-150.
- [14] CHERBUT C, AUBE A C, MEKKI N, et al. Digestive and metabolic effects of potato and maize fibres in human subjects[J]. British Journal of Nutrition, 1997, 77(1): 33-46.
- [15] 吴端钦, 贺志雄. 醋糟在动物营养中应用的研究进展 [J]. 饲料博览, 2011(5): 50-51.
- [16] BELINKY P A, FLIKSHTEIN N, LECHENKO S, et al. Reactive oxygen species and induction of lignin peroxidase in *Phanerochaete chrysosporium*[J]. Applied and Environmental Microbiology, 2003, 69(11): 6500-6506.
- [17] TIEN M, KIRK T K. Lignin-degrading enzyme from the hymenomycete *Phanerochaete chrysosporium* Burds[J]. Science, 1983, 221(4611): 661-663.
- [18] WANG C H, HSEU T H, HUANG C M. Induction of cellulase by cello-oligosaccharides in *Trichoderma koningii* G-39[J]. Journal of Biotechnology, 1988, 9(1): 47-59.
- [19] 邹德勋, 郑瑾, 刘瑛颖, 等. 康氏木霉利用废酒糟产纤维素酶的研究 [J]. 太阳能学报, 2012, 33(3): 355-358.
- [20] SOHAIL M, SIDDIQI R, AHMAD A, et al. Cellulase production from *Aspergillus niger* MS82: effect of temperature and pH[J]. New Biotechnology, 2009, 25(6): 437-441.
- [21] SCHUSTER E, DUNN-COLEMAN N, FRISVAD J C, et al. On the safety of *Aspergillus niger*-a review[J]. Applied Microbiology and Biotechnology, 2002, 59(4/5): 426-435.
- [22] DRIOUCH H, HÄNSCH R, WUCHERPFENNIG T, et al. Improved enzyme production by bio-pellets *Aspergillus niger*: targeted morphology engineering using titanate microparticles[J]. Biotechnology and Bioengineering, 2012, 109(2): 462-471.
- [23] 王志红. 无花果曲霉利用醋糟产植酸酶发酵条件与植酸酶分离纯化及性质的研究 [D]. 博士学位论文. 北京: 中国农业科学院, 2009: 5-15.

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

*Source: ChinaXiv – Machine translation. Verify with original.*