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Effect of *Aspergillus niger* fermented soybean meal and sunflower oil cake on growth, carcass composition and haemolymph indices in *Penaeus vannamei* Boone

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研究背景

鱼粉

适口性差；
抗营养因子；
氨基酸组成不平衡；
蛋白消化率低；

植物蛋白源

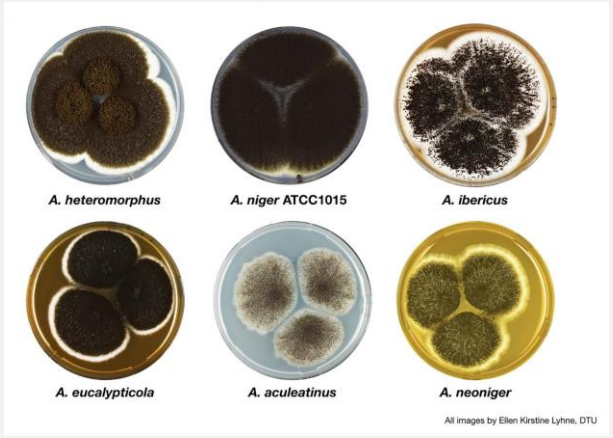
发酵

豆粕
（Soybean meal，SBM）

葵花籽油饼
（Sunflower oil cake， SFC）

- 含硫氨基酸含量不足
- 胰蛋白酶抑制剂
- 纤维含量高，消化率低阻碍生长

菌种：



外观相似的黑曲霉家族

黑曲霉（*Aspergillus niger*），是半知菌亚门、丝孢纲，丝孢目，丛梗孢科、曲霉属中的一个常见种。是自然界广泛分布的对人和动植物**无害的益生真菌**。

黑曲霉是重要的发酵工业菌种，可生产**淀粉酶、酸性蛋白酶、纤维素酶、半纤维素酶、果胶酶、芍药糖氧化酶、脂肪酶、柠檬酸、葡糖酸和没食子酸**等，现已逐渐广泛用于食品发酵工业、发酵饲料、生物肥料生产等，还可以在饲料中直接添加。

◆ 1、由于黑曲霉在生长代谢过程中产生糖化酶，被广泛用来生产**糖化饲料**。

可用来测定锰、铜、钼、锌等微量元素和作为**霉腐试验菌**。

◆ 2、由于黑曲霉在生长代谢过程中可以产生高活力的纤维素酶，被广泛用作**有机肥腐熟剂**。

◆ 3、由于黑曲霉在生长代谢过程中可以产生很多种水解酶，具有消化饲料中的营养物质和**分解抗营养因子**的作用，因此在饲料中添加可以提高饲料利用率、提高动物的生产性能，降低生产成本，改善养殖环境。

发酵及饲料制备

PDA培养基，35℃，5d

1×10^7孢子/ml

5%

豆粕

葵花
籽油饼

35±1℃，3d

50℃，48h
含水量＜10%

饲料制备

实验设计

南美白对虾
(3.08 ±0.07g)

对照组
（Control）：

CNT: 基础饲料。

豆粕组
（Soybeon）：

FSBM200 / SBM200 : 200g/kg发酵 / 未发酵豆粕；
FSBM250 / SBM250 : 250g/kg发酵 / 未发酵豆粕；
FSBM300 / SBM300 : 300g/kg发酵 / 未发酵豆粕；
FSBM350 / SBM350 : 350g/kg发酵 / 未发酵豆粕；
FSBM400 / SBM400 : 400g/kg发酵 / 未发酵豆粕。

葵花籽油饼组
（Sunfiower oil cake）：

FSFC25 / SFC25 : 25g/kg发酵/ 未发酵葵花籽饼；
FSFC50 / SFC50 : 50g/kg发酵/ 未发酵葵花籽饼；
FSFC75 / SFC75 : 75g/kg发酵/ 未发酵葵花籽饼；
FSFC100 / SFC100 : 100g/kg发酵/ 未发酵葵花籽饼。

45d

生长

- 增重(WG)、
- 日增重率(DGC)、
- 饲料转化率(FCR)、
- 蛋白质效率 (PER)、
- 蛋白质利用率(APU)

胴体组成

- 水分
- 粗蛋白、
- 粗脂肪、
- 灰分

血淋巴指数

- 总蛋白
- 葡萄糖、
- 胆固醇、
- 甘油三酯

饲料

Table 1. 鱼粉及发酵产物等的化学组成。

Particulars	Fishmeal	Test ingredients			
		SBM[1]	FSBM[2]	SFC[3]	FSFC[4]
Chemical composition					
粗蛋白 Crude protein	631.67 ± 6.05	524.04 ± 7.37^{b}	598.51 ± 5.34^{a}	356.07 ± 1.41^{y}	375.44 ± 1.65^{x}
乙醚萃取物 Ether extract	105.31 ± 3.40	10.91 ± 0.42^{a}	7.77 ± 0.30^{b}	17.34 ± 0.49^{x}	15.63 ± 1.00^{y}
粗纤维 Crude fiber	5.39 ± 0.33	69.57 ± 2.55^{a}	67.74 ± 2.37^{b}	288.51 ± 7.28^{x}	264.11 ± 7.01^{y}
中性洗涤纤维 Neutral detergent fiber	10.04 ± 0.23	119.24 ± 1.26^{a}	114.73 ± 0.83^{b}	438.61 ± 5.21^{x}	403.66 ± 3.75^{y}
酸性洗涤纤维 Acid detergent fiber	8.16 ± 0.11	78.26 ± 2.36^{a}	73.91 ± 1.66^{b}	275.94 ± 2.03^{x}	257.22 ± 2.90^{y}
无氮浸出物 Nitrogen free extract	68.06 ± 8.36	320.04 ± 5.58^{a}	246.01 ± 7.60^{b}	259.74 ± 8.79^{x}	264.27 ± 7.81^{x}
灰分 Total ash	189.57 ± 5.11	75.44 ± 4.28^{a}	79.97 ± 3.27^{a}	78.34 ± 2.80^{x}	80.55 ± 1.74^{x}
Essential amino acids					
精氨酸 Arginine	43.77 ± 0.75	30.04 ± 2.23^{b}	40.71 ± 2.97^{a}	16.15 ± 1.19^{y}	18.80 ± 0.99^{x}
组氨酸 Histidine	16.94 ± 0.52	17.50 ± 1.69^{b}	19.46 ± 0.99^{a}	4.69 ± 0.58^{y}	5.64 ± 0.64^{x}
异亮氨酸 Isoleucine	29.65 ± 0.53	27.26 ± 0.59^{b}	29.04 ± 0.52^{a}	33.65 ± 0.58^{x}	33.70 ± 0.65^{x}
亮氨酸 Leucine	50.83 ± 0.83	39.27 ± 0.76^{a}	40.09 ± 0.60^{a}	14.59 ± 0.77^{y}	18.70 ± 1.10^{x}
赖氨酸 Lysine	52.95 ± 0.60	12.49 ± 1.62^{b}	40.08 ± 2.24^{a}	11.80 ± 1.88^{y}	23.10 ± 2.80^{x}
甲硫氨酸 Methionine	19.06 ± 0.29	7.41 ± 1.13^{b}	9.90 ± 0.75^{a}	17.00 ± 1.59^{x}	17.75 ± 0.94^{x}
苯丙氨酸 Phenylalanine	27.53 ± 0.55	20.25 ± 1.00^{b}	25.24 ± 1.11^{a}	16.04 ± 0.90^{y}	17.20 ± 0.55^{x}
苏氨酸 Threonine	28.95 ± 1.05	17.15 ± 1.17^{b}	19.09 ± 0.53^{a}	10.25 ± 1.07^{y}	15.00 ± 1.28^{x}
苏氨酸 Tryptophan	7.06 ± 0.29	6.70 ± 0.47^{b}	7.70 ± 0.39^{a}	4.20 ± 0.45^{x}	4.40 ± 0.34^{x}
缬氨酸 Valine	34.59 ± 0.93	16.29 ± 0.75^{b}	17.55 ± 1.06^{a}	14.80 ± 0.96^{x}	14.90 ± 1.05^{x}
Anti-nutritional factors					
胰蛋白酶抑制剂 Trypsin inhibitor	–	2.41 ± 0.03^{a}	0.14 ± 0.02^{b}	nd[5]	nd[5]
植酸 Phytic acid	–	13.36 ± 0.23^{a}	6.53 ± 0.15^{b}	nd[5]	nd[5]
单宁 Tannin	–	nd[5]	nd[5]	8.79 ± 0.17^{x}	6.10 ± 0.09^{y}
皂苷 Saponin	–	10.03 ± 0.01^{a}	2.10 ± 0.06^{b}	6.42 ± 0.37^{x}	2.17 ± 0.21^{y}

饲料

Table 2. 豆粕为原料的实验日粮成分及必需氨基酸组成。

Ingredients	Control diet (CNT)	Diets with test ingredients							
		SBM 250	SBM 300	SBM 350	SBM 400	FSBM 250	FSBM 300	FSBM 350	FSBM 400
Fishmeal[1]	250	200	150	100	50	200	150	100	50
SBM[2]	200	250	300	350	400	–	–	–	–
FSBM[3]	–	–	–	–	–	250	300	350	400
Acetes[4]	80	80	80	80	80	80	80	80	80
Squid meal	15	15	15	15	15	15	15	15	15
Corn gluten	20	33	40	47	54	24	28	32	36
Sesame cake	50	50	50	50	50	50	50	50	50
Wheat flour	324	306	294	282	270	315	306	297	288
Fish oil[1]	20	20	20	20	20	20	20	20	20
Palm oil	–	5	10	15	20	5	10	15	20
Lecithin	10	10	10	10	10	10	10	10	10
Pre-mix[5]	20	20	20	20	20	20	20	20	20
Binder[6]	10	10	10	10	10	10	10	10	10
BHT[7]	1	1	1	1	1	1	1	1	1
Proximate composition									
Moisture	87.6 ± 1.3^{a}	88.2 ± 0.6^{a}	86.2 ± 1.0^{a}	86.7 ± 1.8^{a}	87.6 ± 1.2^{a}	88.2 ± 0.7^{a}	87.0 ± 1.3^{a}	87.1 ± 0.2^{a}	87.3 ± 1.2^{a}
Crude protein	374.4 ± 5.3^{a}	367.4 ± 8.3^{a}	363.8 ± 9.9^{a}	364.6 ± 3.4^{a}	365.6 ± 2.5^{a}	372.6 ± 5.0^{a}	371.4 ± 7.2^{a}	369.8 ± 4.4^{a}	376.5 ± 6.7^{a}
Ether extract	67.6 ± 1.0^{a}	69.4 ± 0.9^{a}	70.1 ± 1.4^{a}	71.1 ± 0.9^{a}	70.1 ± 2.0^{a}	69.8 ± 2.6^{a}	71.1 ± 0.6^{a}	71.5 ± 1.5^{a}	72.2 ± 2.0^{a}
Crude fiber	29.8 ± 1.5^{f}	30.1 ± 1.2^{f}	33.7 ± 1.9^{d}	36.3 ± 1.5^{c}	38.7 ± 1.5^{a}	29.8 ± 0.9^{f}	32.6 ± 1.1^{e}	36.2 ± 1.0^{c}	37.6 ± 1.2^{b}
NDF[8]	291.9 ± 1.7^{g}	297.3 ± 3.7^{f}	333.1 ± 2.6^{d}	356.2 ± 4.1^{c}	381.4 ± 0.5^{a}	291.1 ± 2.4^{g}	319.5 ± 2.3^{e}	354.0 ± 1.8^{c}	367.5 ± 3.8^{b}
ADF[9]	124.6 ± 2.0^{g}	128.8 ± 4.0^{f}	142.7 ± 3.4^{d}	155.4 ± 3.0^{b}	165.4 ± 2.7^{a}	125.0 ± 7.0^{g}	132.3 ± 2.9^{e}	148.4 ± 2.4^{c}	155.0 ± 3.4^{b}
NFE[10]	297.1 ± 8.5^{c}	311.3 ± 11.8^{cd}	324.0 ± 11.5^{ab}	324.9 ± 6.8^{ab}	327.1 ± 4.3^{a}	305.4 ± 10.5^{de}	315.1 ± 13.7^{bcd}	319.6 ± 6.9^{abc}	315.5 ± 10.8^{bcd}
Total ash	143.5 ± 2.3^{a}	133.6 ± 2.8^{b}	122.2 ± 1.6^{c}	116.4 ± 1.3^{d}	110.9 ± 1.5^{e}	134.2 ± 3.0^{b}	122.8 ± 3.6^{c}	115.8 ± 1.7^{d}	110.9 ± 2.7^{e}
Essential amino acids									
Arginine	23.1 ± 0.6^{a}	23.8 ± 1.7^{a}	24.7 ± 1.0^{a}	25.1 ± 1.1^{a}	23.7 ± 0.9^{a}	24.2 ± 1.2^{a}	26.4 ± 1.7^{a}	23.9 ± 1.4^{a}	25.3 ± 1.7^{a}
Histidine	8.8 ± 0.6^{a}	8.6 ± 0.8^{a}	9.0 ± 0.7^{a}	9.1 ± 0.6^{a}	8.7 ± 0.3^{a}	9.1 ± 0.5^{a}	9.4 ± 0.6^{a}	9.3 ± 0.5^{a}	10.1 ± 1.1^{a}
Isoleucine	15.3 ± 0.9^{a}	15.6 ± 1.1^{a}	15.2 ± 0.9^{a}	15.7 ± 0.6^{a}	16.2 ± 0.6^{a}	15.6 ± 0.4^{a}	15.8 ± 0.2^{a}	16.9 ± 1.0^{a}	16.3 ± 0.8^{a}
Leucine	26.4 ± 0.9^{a}	27.5 ± 1.2^{a}	27.9 ± 2.0^{a}	26.9 ± 1.8^{a}	28.8 ± 2.1^{a}	26.7 ± 2.1^{a}	27.3 ± 1.5^{a}	27.2 ± 1.6^{a}	27.5 ± 2.9^{a}
Lysine	21.4 ± 1.1^{a}	20.9 ± 0.9^{a}	21.1 ± 1.2^{a}	19.7 ± 2.0^{a}	19.1 ± 2.0^{a}	21.2 ± 2.1^{a}	22.2 ± 2.1^{a}	20.8 ± 2.3^{a}	21.4 ± 2.6^{a}
Methionine	8.4 ± 0.4^{a}	8.2 ± 0.3^{a}	7.7 ± 0.4^{abcd}	6.9 ± 0.7^{e}	7.0 ± 0.5^{de}	8.0 ± 0.2^{ab}	7.8 ± 0.3^{abc}	7.4 ± 0.8^{bcde}	7.2 ± 0.3^{cde}
Phenylalanine	17.3 ± 0.5^{a}	17.9 ± 1.0^{a}	18.7 ± 0.7^{a}	18.3 ± 0.4^{a}	19.1 ± 0.9^{a}	17.6 ± 1.2^{a}	18.7 ± 2.0^{a}	18.1 ± 1.0^{a}	19.1 ± 1.2^{a}
Threonine	14.3 ± 0.6^{a}	13.9 ± 1.0^{a}	14.2 ± 1.3^{a}	14.1 ± 0.9^{a}	13.5 ± 0.1^{a}	14.1 ± 0.4^{a}	13.9 ± 0.1^{a}	14.7 ± 0.8^{a}	13.5 ± 0.9^{a}
Tryptophan	4.2 ± 0.4^{a}	3.9 ± 0.3^{a}	3.8 ± 0.4^{a}	4.3 ± 0.5^{a}	4.1 ± 0.3^{a}	4.2 ± 0.4^{a}	4.8 ± 0.3^{a}	4.4 ± 0.5^{a}	4.7 ± 0.3^{a}
Valine	17.1 ± 0.5^{a}	16.7 ± 0.7^{a}	17.2 ± 0.6^{a}	17.8 ± 0.8^{a}	17.1 ± 0.9^{a}	16.7 ± 0.9^{a}	16.8 ± 0.8^{a}	15.7 ± 0.9^{a}	15.3 ± 1.0^{a}

中性洗涤纤维
酸性洗涤纤维
无氮浸出物

精氨酸
组氨酸
异亮氨酸
亮氨酸
赖氨酸
甲硫氨酸
苯丙氨酸
苏氨酸
色氨酸
缬氨酸

饲料

Table 3. 葵花籽油饼为原料的实验日粮成分及必需氨基酸组成。

Ingredients	Control diet (CNT)	Diets with test ingredients							
		SFC 25	SFC 50	SFC 75	SFC 100	FSFC 25	FSFC 50	FSFC 75	FSFC 100
Fishmeal[1]	250	225	200	175	150	225	200	175	150
SFC[2]	–	25	50	75	100	–	–	–	–
FSFC[3]	–	–	–	–	–	25	50	75	100
Acetes[4]	80	80	80	80	80	80	80	80	80
Squid meal	15	15	15	15	15	15	15	15	15
Soybean meal	200	200	200	200	200	200	200	200	200
Corn gluten	20	29	39	49	59	27	34	42	50
Sesame cake	50	50	50	50	50	50	50	50	50
Wheat flour	324	313	301	289	277	315	306	296	286
Fish oil[1]	20	20	20	20	20	20	20	20	20
Palm oil	–	2	4	6	8	2	4	6	8
Lecithin	10	10	10	10	10	10	10	10	10
Pre-mix[5]	20	20	20	20	20	20	20	20	20
Binder[6]	10	10	10	10	10	10	10	10	10
BHT[7]	1	1	1	1	1	1	1	1	1
Proximate composition									
Moisture	87.6 ± 1.3^{a}	86.5 ± 1.5^{a}	78.9 ± 7.2^{a}	80.1 ± 8.5^{a}	82.3 ± 4.0^{a}	84.5 ± 1.3^{a}	86.7 ± 1.1^{a}	78.5 ± 6.9^{a}	79.5 ± 6.4^{a}
Crude protein	374.4 ± 5.3^{a}	375.3 ± 8.8^{a}	380.4 ± 9.1^{a}	367.4 ± 7.9^{a}	370.8 ± 6.9^{a}	374.3 ± 6.4^{a}	381.7 ± 8.3^{a}	369.9 ± 5.3^{a}	371.7 ± 7.4^{a}
Ether extract	67.6 ± 1.0^{a}	70.0 ± 5.3^{a}	71.5 ± 1.3^{a}	69.8 ± 1.8^{a}	70.1 ± 0.6^{a}	71.3 ± 1.6^{a}	70.5 ± 1.0^{a}	69.7 ± 2.0^{a}	68.5 ± 1.2^{a}
Crude fiber	29.8 ± 1.5^{e}	34.6 ± 2.5^{d}	40.9 ± 2.6^{c}	47.2 ± 1.7^{b}	53.4 ± 1.6^{a}	34.4 ± 1.0^{d}	40.4 ± 2.4^{c}	46.4 ± 2.9^{b}	52.4 ± 1.2^{a}
NDF[8]	291.9 ± 1.7^{i}	345.0 ± 0.9^{g}	403.8 ± 4.6^{e}	465.8 ± 1.9^{c}	528.7 ± 1.2^{a}	334.8 ± 1.2^{h}	394.8 ± 4.7^{f}	452.7 ± 1.5^{d}	513.5 ± 2.9^{b}
ADF[9]	124.6 ± 2.0^{i}	149.2 ± 3.0^{g}	172.6 ± 2.0^{e}	201.7 ± 1.7^{c}	226.8 ± 3.8^{a}	144.2 ± 3.4^{h}	163.2 ± 3.8^{f}	192.5 ± 2.2^{d}	216.6 ± 1.1^{b}
NFE[10]	297.1 ± 8.5^{a}	303.2 ± 17.6^{a}	300.7 ± 27.9^{a}	310.8 ± 36.8^{a}	301.5 ± 14.0^{a}	305.0 ± 12.6^{a}	292.8 ± 13.2^{a}	310.3 ± 18.9^{a}	305.4 ± 17.2^{a}
Total ash	143.5 ± 2.3^{a}	130.4 ± 1.5^{b}	127.6 ± 2.0^{c}	124.7 ± 2.2^{d}	121.8 ± 1.5^{e}	130.6 ± 2.4^{b}	127.9 ± 0.8^{c}	125.2 ± 3.3^{d}	122.5 ± 2.3^{e}
Essential amino acids									
Arginine	23.1 ± 0.6^{a}	22.8 ± 0.9^{a}	26.4 ± 2.9^{a}	22.3 ± 1.7^{a}	22.1 ± 1.3^{a}	24.8 ± 1.4^{a}	22.6 ± 0.8^{a}	23.7 ± 1.0^{a}	22.7 ± 1.8^{a}
Histidine	8.8 ± 0.6^{a}	8.7 ± 0.4^{a}	8.3 ± 0.5^{a}	8.9 ± 0.4^{a}	7.8 ± 0.7^{a}	8.7 ± 0.8^{a}	9.1 ± 0.8^{a}	8.5 ± 0.5^{a}	8.1 ± 0.3^{a}
Isoleucine	15.3 ± 0.9^{a}	15.8 ± 1.0^{a}	16.8 ± 1.0^{a}	16.4 ± 1.3^{a}	17.2 ± 0.7^{a}	16.2 ± 0.8^{a}	15.5 ± 0.8^{a}	16.5 ± 0.9^{a}	16.9 ± 0.5^{a}
Leucine	26.4 ± 0.9^{a}	27.1 ± 1.6^{a}	26.8 ± 0.8^{a}	25.9 ± 1.1^{a}	27.2 ± 0.9^{a}	26.7 ± 2.3^{a}	26.6 ± 0.8^{a}	27.3 ± 0.5^{a}	27.7 ± 1.3^{a}
Lysine	21.4 ± 1.1^{a}	20.7 ± 1.3^{a}	20.4 ± 0.9^{a}	18.6 ± 1.2^{a}	19.4 ± 0.6^{a}	21.0 ± 1.4^{a}	19.6 ± 1.9^{a}	22.7 ± 2.3^{a}	20.9 ± 0.9^{a}
Methionine	8.4 ± 0.4^{a}	7.8 ± 0.6^{a}	7.3 ± 2.1^{a}	8.4 ± 0.6^{a}	8.9 ± 0.3^{a}	8.1 ± 0.6^{a}	7.7 ± 0.7^{a}	7.4 ± 0.4^{a}	8.8 ± 0.4^{a}
Phenylalanine	17.3 ± 0.5^{a}	17.1 ± 1.1^{a}	17.7 ± 0.8^{a}	18.0 ± 0.5^{a}	18.2 ± 0.4^{a}	17.8 ± 0.6^{a}	17.3 ± 1.1^{a}	18.0 ± 0.8^{a}	18.1 ± 0.8^{a}
Threonine	14.3 ± 0.6^{a}	15.1 ± 0.5^{a}	14.8 ± 0.8^{a}	14.4 ± 0.5^{a}	13.7 ± 0.4^{a}	14.0 ± 0.7^{a}	14.4 ± 0.6^{a}	15.2 ± 1.4^{a}	14.3 ± 1.2^{a}
Tryptophan	4.2 ± 0.4^{a}	3.8 ± 0.9^{a}	4.3 ± 1.2^{a}	4.4 ± 0.4^{a}	4.7 ± 0.9^{a}	4.4 ± 0.6^{a}	4.8 ± 0.7^{a}	5.1 ± 0.4^{a}	3.9 ± 0.7^{a}
Valine	17.1 ± 0.5^{a}	17.4 ± 0.9^{a}	16.8 ± 1.0^{a}	17.3 ± 1.3^{a}	17.8 ± 1.1^{a}	16.9 ± 1.1^{a}	17.4 ± 1.9^{a}	16.6 ± 1.1^{a}	17.0 ± 1.0^{a}

Table 4. 豆粕发酵产物替代鱼粉后，对南美白对虾生长性能、胴体组成和血淋巴指数的影响。

Particulars	Control diet (CNT)	Diets with test ingredients								SEM	*P*-value
		SBM 250	SBM 300	SBM 350	SBM 400	FSBM 250	FSBM 300	FSBM 350	FSBM 400		
Initial wt (g)	3.06^{a}	3.13^{a}	3.06^{a}	3.04^{a}	3.06^{a}	3.05^{a}	3.08^{a}	3.08^{a}	3.10^{a}	0.003	0.832
Final wt (g)	9.52^{a}	9.78^{a}	8.81^{b}	8.48^{bc}	8.23^{c}	9.67^{a}	9.60^{a}	9.35^{a}	8.79^{b}	0.049	< 0.001
Weight gain (%)	211.65^{a}	212.73^{a}	188.15^{b}	179.44^{bc}	169.41^{c}	216.48^{a}	211.80^{a}	203.25^{a}	183.96^{b}	39.238	< 0.001
日增重率 DGC[1]	1.48^{a}	1.50^{a}	1.36^{b}	1.31^{bc}	1.26^{c}	1.51^{a}	1.49^{a}	1.44^{a}	1.35^{b}	0.001	< 0.001
饲料转化率 FCR[2]	1.86^{c}	1.81^{c}	2.09^{b}	2.20^{ab}	2.32^{a}	1.82^{c}	1.84^{c}	1.92^{c}	2.11^{b}	0.003	< 0.001
蛋白效率 PER[3]	1.44^{a}	1.51^{a}	1.32^{bc}	1.24^{cd}	1.18^{d}	1.48^{a}	1.46^{a}	1.41^{ab}	1.26^{cd}	0.002	< 0.001
蛋白利用率 APU[4]	23.59^{a}	24.75^{a}	21.60^{bc}	20.40^{cd}	19.35^{d}	24.23^{a}	23.98^{a}	23.15^{ab}	20.67^{cd}	0.546	< 0.001
Survival (%)	93.33^{a}	86.67^{a}	93.33^{a}	86.67^{a}	96.67^{a}	90.00^{a}	86.67^{a}	93.33^{a}	86.67^{a}	40.628	0.730
Carcass composition (g/kg wet basis)											
Moisture	78.10^{a}	78.61^{a}	78.56^{a}	78.58^{a}	78.85^{a}	78.62^{a}	77.38^{a}	78.27^{a}	78.66^{a}	0.167	0.107
Crude protein	16.34^{a}	15.99^{a}	16.03^{a}	15.95^{a}	15.78^{a}	15.92^{a}	16.86^{a}	16.13^{a}	15.90^{a}	0.112	0.180
Ether extract	0.88^{b}	1.08^{a}	1.02^{a}	1.02^{a}	1.03^{a}	0.99^{a}	1.07^{a}	1.07^{a}	1.06^{a}	0.002	0.026
Total ash	2.91^{a}	2.92^{a}	2.89^{a}	2.76^{a}	2.86^{a}	2.86^{a}	3.01^{a}	3.01^{a}	2.91^{a}	0.006	0.503
血淋巴指数 Haemolymph indices											
总蛋白 Total protein (g/dl)	9.28^{a}	8.18^{c}	8.19^{c}	7.47^{d}	6.23^{e}	8.84^{ab}	8.10^{c}	8.25^{bc}	6.35^{e}	0.074	< 0.001
葡萄糖 Glucose (g/dl)	1.45^{d}	1.55^{cd}	1.61^{bc}	1.67^{bc}	1.81^{a}	1.48^{d}	1.66^{b}	1.65^{bc}	1.81^{a}	0.002	< 0.001
胆固醇 Cholesterol (mg/dl)	23.98^{a}	22.40^{b}	19.58^{c}	17.34^{ef}	15.93^{fg}	21.82^{b}	19.45^{cd}	17.99^{de}	15.71^{g}	0.447	< 0.001
甘油三酯 Triglycerides (mg/dl)	65.52^{a}	61.23^{ab}	56.09^{c}	46.41^{d}	35.86^{e}	65.14^{a}	56.90^{bc}	43.72^{d}	37.67^{e}	3.729	< 0.001

超过FSBM250组各指标下降，超过FSBM350组显著下降*P*＜0.05。

Table 5.葵花籽油饼发酵产物替代鱼粉后，对南美白对虾生长性能、胴体组成和血淋巴指数的影响。

Particulars	Control diet (CNT)	Diets with test ingredients								SEM	*P*-value
		SFC 25	SFC 50	SFC 75	SFC 100	FSFC 25	FSFC 50	FSFC 75	FSFC 100		
Initial wt (g)	3.06^{a}	3.07^{a}	3.13^{a}	3.05^{a}	3.08^{a}	3.13^{a}	3.13^{a}	3.05^{a}	3.08^{a}	0.004	0.871
Final wt (g)	9.52^{a}	9.38^{ab}	9.15^{bc}	8.75^{de}	8.58^{e}	9.65^{a}	9.45^{ab}	8.93^{cd}	8.81^{de}	0.020	< 0.001
Weight gain (%)	211.65^{a}	205.50^{ab}	192.54^{bc}	186.64^{cd}	178.69^{d}	208.66^{a}	202.57^{ab}	192.41^{bcd}	185.93^{cd}	36.655	< 0.001
日增重率 DGC[1]	1.48^{a}	1.45^{ab}	1.40^{bc}	1.35^{cd}	1.31^{d}	1.48^{a}	1.45^{ab}	1.38^{cd}	1.35^{cd}	0.001	0.001
饲料转化率 FCR[2]	1.86^{e}	1.90^{de}	1.99^{cd}	2.11^{ab}	2.18^{a}	1.84^{e}	1.90^{e}	2.04^{bc}	2.10^{ab}	0.002	< 0.001
蛋白效率 PER[3]	1.44^{ab}	1.40^{ab}	1.32^{cd}	1.29^{de}	1.24^{e}	1.45^{ab}	1.38^{bc}	1.32^{cd}	1.28^{de}	0.001	< 0.001
蛋白利用率 APU[4]	23.59^{ab}	23.16^{ab}	21.80^{cd}	21.37^{de}	20.45^{e}	24.01^{ab}	22.84^{bc}	21.87^{cd}	21.22^{de}	0.225	< 0.001
Survival (%)	93.33^{a}	96.67^{a}	90.00^{a}	86.67^{a}	83.33^{a}	86.67^{a}	93.33^{a}	86.67^{a}	90.00^{a}	58.270	0.816
Carcass composition (g/kg wet basis)											
Moisture	78.10^{a}	78.61^{a}	78.60^{a}	78.70^{a}	78.59^{a}	78.57^{a}	78.09^{a}	77.78^{a}	78.48^{a}	0.100	0.160
Crude protein	16.34^{a}	15.98^{a}	15.98^{a}	15.84^{a}	15.93^{a}	15.93^{a}	16.28^{a}	16.42^{a}	15.97^{a}	0.064	0.349
Ether extract	0.88^{c}	1.02^{ab}	0.97^{ab}	0.95^{bc}	0.98^{ab}	0.95^{bc}	1.00^{ab}	1.04^{a}	1.00^{ab}	0.001	0.029
Total ash	2.91^{a}	2.91^{a}	2.88^{a}	2.72^{a}	2.89^{a}	2.86^{a}	2.91^{a}	3.08^{a}	2.92^{a}	0.007	0.249
血淋巴指数 Haemolymph indices											
总蛋白 Total protein (g/dl)	9.28^{a}	8.48^{bc}	7.95^{c}	7.32^{d}	6.62^{e}	8.84^{ab}	8.17^{c}	8.29^{bc}	7.06^{de}	0.069	< 0.001
葡萄糖 Glucose (g/dl)	1.45^{d}	1.52^{d}	1.61^{c}	1.69^{bc}	1.81^{a}	1.42^{d}	1.64^{c}	1.68^{c}	1.77^{ab}	0.002	< 0.001
胆固醇 Cholesterol (mg/dl)	23.98^{a}	22.19^{b}	19.25^{c}	17.67^{d}	16.11^{ef}	21.78^{b}	20.12^{c}	17.65^{de}	14.97^{f}	0.464	< 0.001
甘油三酯 Triglycerides (mg/dl)	65.52^{a}	61.80^{a}	54.70^{b}	46.75^{c}	35.55^{d}	64.04^{a}	55.42^{b}	43.40^{c}	36.26^{d}	4.135	< 0.001

超过FSFC25组各项指标下降，超过FSFC50组具有显著性$P<0.05$。

替代水平

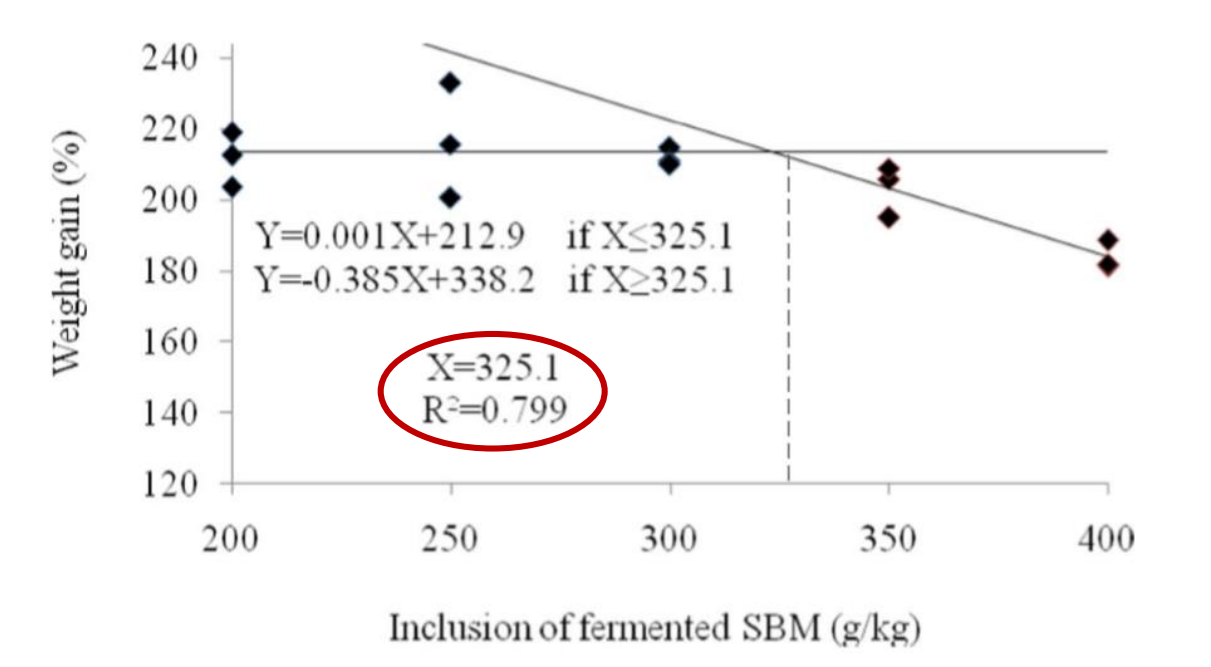


Fig. 1.利用断线分析法，估算发酵SBM在南美白对虾日粮中的最佳替代水平

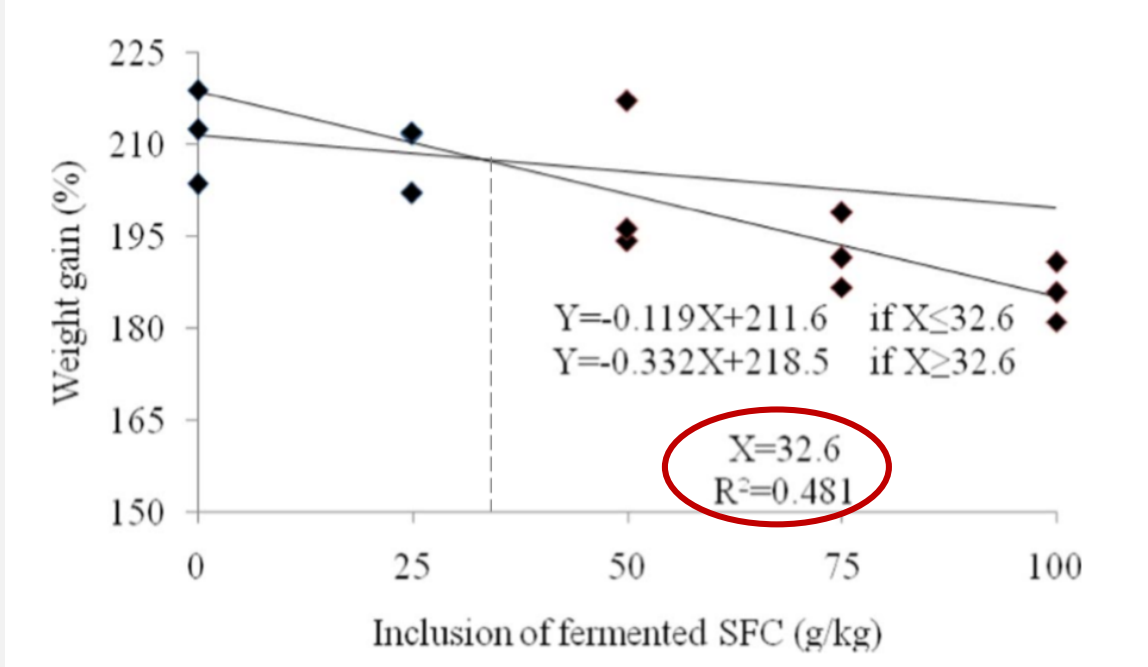


Fig. 2.利用断线分析方法，估算发酵SFC在南美白对虾日粮中的最佳替代水平

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Effect of feeding *Aspergillus niger*-fermented *Ginkgo biloba*-leaves on growth, small intestinal structure and function of broiler chicks

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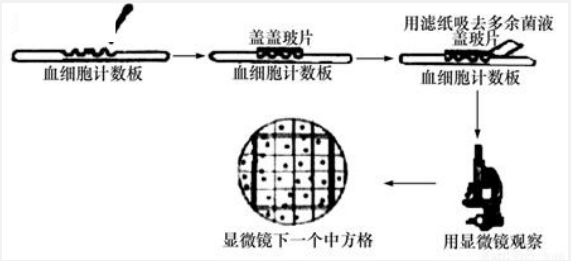
银杏（*ginkgo*），是我国的传统草本植物。在炎症、心血管疾病和癌症的治疗中表现出较高的生理活性。银杏叶黄酮含量较高，**活性成分除黄酮外还有多糖和萜类等**。银杏黄酮类化合物因其抗菌、神经保护、抗突变、改善心血管健康、抗肿瘤活性等方面引起了人们的广泛关注。

银杏叶每年种植产量约**40万吨**，主要分布在江苏，山东，四川，浙江。作为一种可利用的植物资源，在饲料工业中具有潜在经济价值。为了促进银杏叶的加工，我们开发了一种**黑曲霉发酵工艺**，该工艺保留并增强了这种资源的功能。本研究旨在探讨发酵银杏叶是否可以通过刺激宿主生长、粘膜结构或同时刺激小肠，从而通过主肠功能改善宿主肠道健康。

饲料制备



4.0×10^{6}孢子/ml

1%

发酵培养基：

- ✓ 银杏叶:麦麸:玉米芯=8:1.5:0.5
- ✓ 16毫升营养盐溶液 (葡萄糖；尿素；$(NH4)_2SO_4$；蛋白胨；KH_2PO_4；$MgSO_4.7H20$）

24℃，48h

30-40℃/6d,自然晾干

实验设计

51.32±2.32g

	Starter phase 1-21d	Grower phase 22-42d
◆ **CN：**	基础饲料	
◆ **NF：**	基础饲料+0.35%未发酵银杏叶	基础饲料+0.7%未发酵银杏叶
◆ **FR1：**	基础饲料+0.2%发酵银杏叶	基础饲料+0.4%发酵银杏叶
◆ **FR2：**	基础饲料+0.35%发酵银杏叶	基础饲料+0.7%发酵银杏叶
◆ **FR3：**	基础饲料+0.5%发酵银杏叶	基础饲料+1.0%发酵银杏叶

饲料

- 营养成分
- 活性成分

生长

- 日增重
- 日采食量
- 饲料转化率

肠道

- 酶活力：AKP、Pro-、Amy-、Lip-
- 形态结构：绒毛、隐窝
- qPCR:SGLT1

血浆

- D-木糖
- 血浆尿素氮（SUN）

饲料

Table 1. 发酵前后主要营养成分及氨基酸含量的变化

总黄酮 多糖 蛋白 氨基酸 银杏酸

Ginkgo leaves	Total flavonoids/mg of quercetin equivalents/g	Polysaccharides/ g/kg	Protein/g/kg	Total amino acid/g/kg	Total ginkgolic acid g/kg
Before	9.7	4.37	103.7	76.33	1.665
After	9.4	6.51	179.9	92.55	0.045
Increasement	−0.3	2.24	76.2	16.22	−1.620

Concentration of amino acid (g/kg)

Indispensable	Before	After	Dispensable	Before	After
Lysine	4.279	5.235	Aspartate	8.779	11.305
Threonine	3.325	4.273	Serine	3.918	4.726
Leucine	5.049	6.605	Glutamic acid	12.559	15.015
Isoleucine	3.019	3.945	Alanine	4.319	5.605
Methionine	0.666	0.572	Cystine	0.295	0.321
Tryptophan	0.244	0.931	Valine	4.239	5.435
Phenylalanine	3.929	4.915	Proline	5.879	5.615
Tyrosine	2.077	2.733	Total	39.988	48.022
Histidine	3.719	3.615	Increasement	8.034	
Glycine	5.909	6.735			
Arginine	4.126	4.972			
Total	36.342	44.531			
Increasement	8.189				

饲料

Table 2 肉鸡日粮中总黄酮和多糖的含量。

Dietary treatments[1]	Total flavonoids/mg of quercetin equivalent/kg		Total polysaccharides/ mg/kg	
	1–21 d	22–42 d	1–21 d	22–42 d
Cont.	0.095	0.072	0.061	0.055
NF	0.508	1.017	0.213	0.423
FR1	0.290	0.581	0.202	0.405
FR2	0.508	1.017	0.354	0.708
FR3	0.726	1.452	0.506	1.012

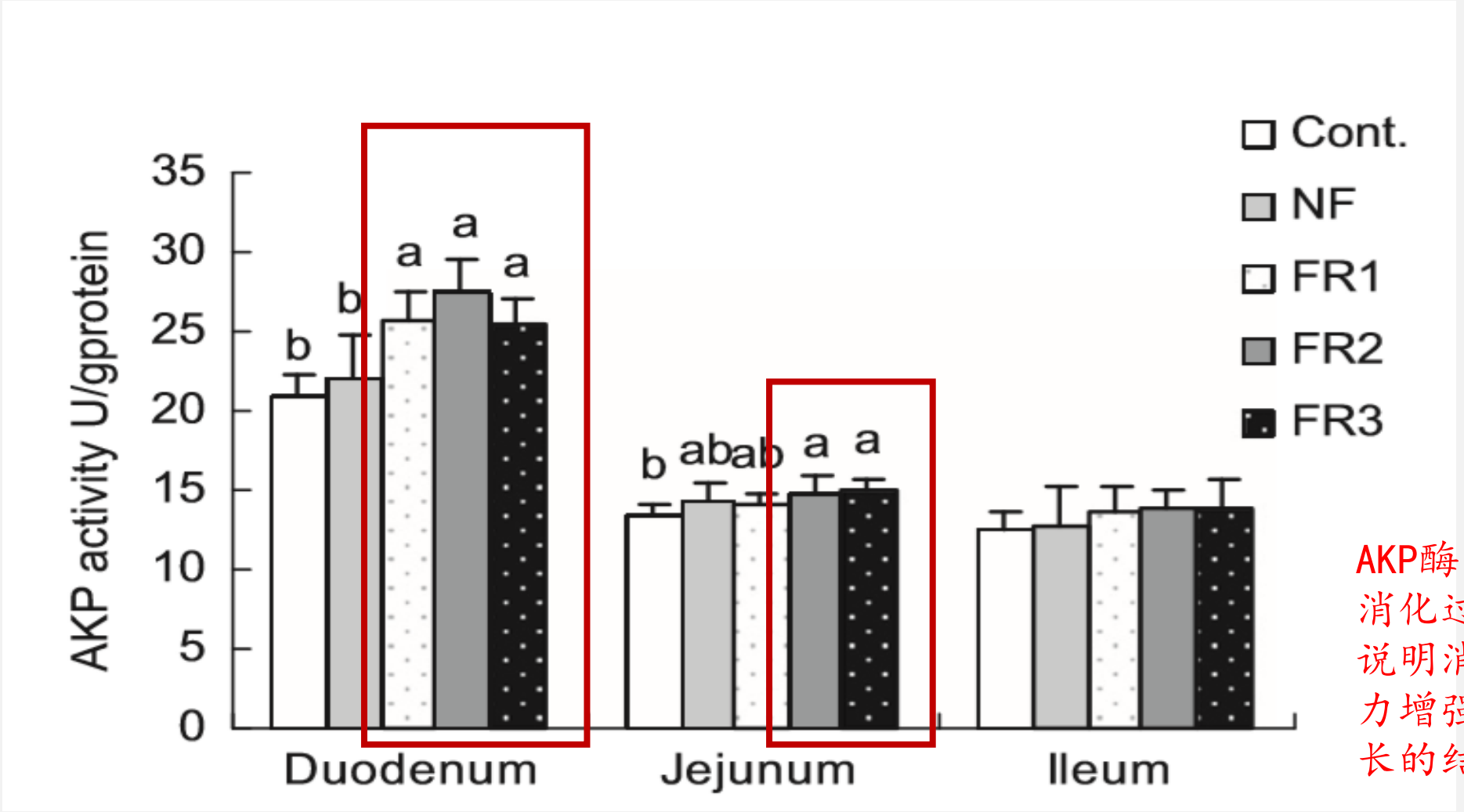
生长

Table 3 发酵银杏叶对肉鸡生长性能的影响。

Item	Dietary treatments[1]					SEM[2]	Contrasts, *P*-value	
	Cont.	NF	FR1	FR2	FR3		Linear	Quadratic
BWG, g/bird/d[3] 日增重								
1–21 d	26.67	26.65	27.71	27.89	26.57	0.216	0.861	0.115
22–42 d	73.58	74.74	74.39	74.09	74.16	0.678	0.773	0.934
1–42 d	50.13	50.69	51.06	50.99	50.36	0.340	0.829	0.611
FI, g/bird/d[3] 日采食量								
1–21 d	41.98	41.94	42.37	44.34	42.10	0.550	0.807	0.653
22–42 d	135.08	136.85	130.09	125.98	131.54	1.480	0.647	0.212
1–42 d	88.53	89.39	85.16	86.23	86.82	0.773	0.601	0.454
F/G[3] 饲料转化率								
1–21 d	1.51	1.50	1.46	1.49	1.46	0.021	0.495	0.785
22–42 d	1.75[a]	1.74[a]	1.66[ab]	1.61[b]	1.73[ab]	0.018	0.934	0.001
1–42 d	2.00[a]	2.00[a]	1.91[ab]	1.89[b]	1.96[ab]	0.014	0.329	0.007

肠道

Fig. 1. 发酵银杏叶对42 d龄肉鸡小肠黏膜(空肠远端)AKP活性的影响。



AKP酶活力参与消化过程，升高说明消化吸收能力增强是刺激生长的结果。

肠道

Table 6 发酵银杏叶对42 d肉鸡小肠形态的影响。

Item	Dietary treatments[1]					SEM[2]	Contrasts, *P*-value	
	Cont.	NF	FR1	FR2	FR3		Linear	Quadratic
十二指肠 Duodenum								
Villous height (μm) 绒毛高度	1558^{b}	1633^{ab}	1689^{a}	1679^{a}	1684^{a}	15.65	0.004	0.004
Crypt depth (μm) 隐窝深度	216.4	216.0	214.8	213.5	210.3	2.87	0.479	0.759
Villous height to crypt depth ratio	7.25	7.60	7.88	7.87	8.10	0.13	0.241	0.378
空肠 Jejunum								
Villous height (μm)	1141^{b}	1162^{b}	1220^{ab}	1295^{a}	1260^{ab}	19.21	0.004	0.014
Crypt depth (μm)	193.2^{a}	189.7^{a}	178.9^{b}	177.1^{b}	178.8^{b}	1.13	0.001	0.001
Villous height to crypt depth ratio	5.92^{b}	6.13^{b}	6.83^{ab}	7.32^{a}	7.06^{a}	0.14	0.564	0.455
回肠 Ileum								
Villous height (μm)	819	817	826	851	861	13.05	0.208	0.431
Crypt depth (μm)	109.48	103.53	100.49	106.26	99.61	1.89	0.209	0.414
Villous height to crypt depth ratio	7.51	7.89	8.31	8.67	8.18	0.19	0.684	0.917

绒毛高度：表征动物的消化吸收能力。**隐窝深度**：决定肠绒毛有丝分裂生成上皮细胞的速度，反映细胞生成率，而隐窝变浅，表明细胞成熟率上升，分泌功能增强。**绒毛高度/隐窝深度**：可综合反映小肠消化吸收功能状况。

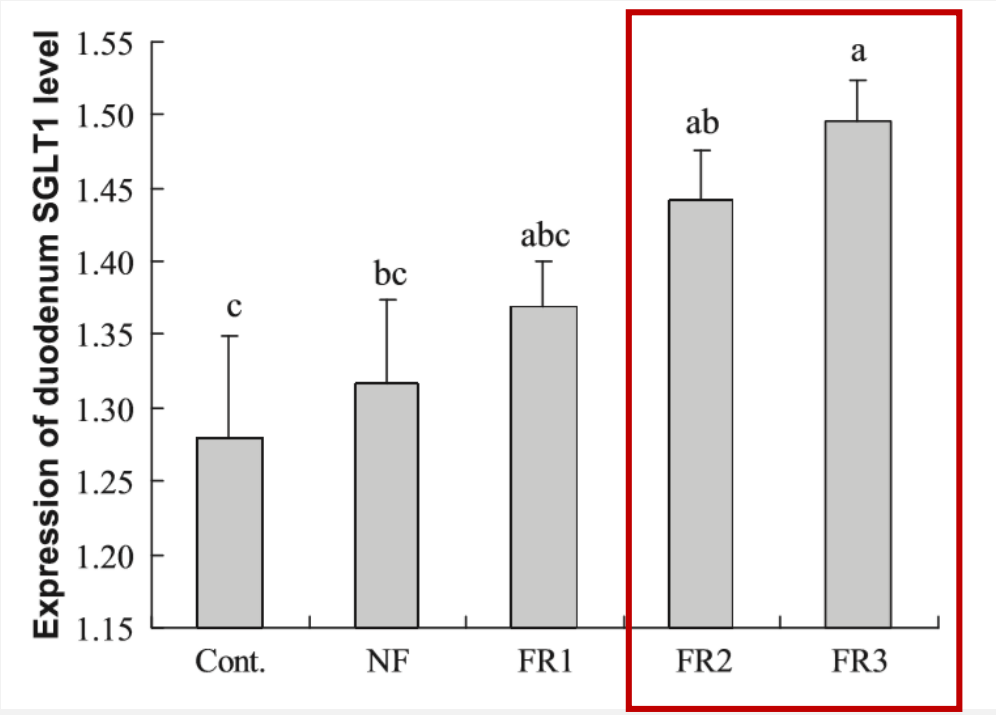
肠道、胰腺

Table 7 发酵银杏叶对肉鸡胰腺消化酶活性的影响。

Item	Dietary treatments[1]					SEM[2]	Contrasts, *P*-value	
	Cont.	NF	FR1	FR2	FR3		Linear	Quadratic
Pancreas 胰腺								
Protease, unit[3] 蛋白酶	144.47^{b}	148.97^{b}	149.00^{b}	155.87^{a}	158.63^{a}	1.28	0.001	0.003
Lipase, Sigma-Tietz unit[4] 脂肪酶	39.16	39.63	44.57	43.90	43.12	0.84	0.348	0.653
Amylase, Somogyi unit[5] 淀粉酶	43.63	43.87	45.71	45.92	44.84	1.22	0.474	0.654
Duodenum 十二指肠								
Protease, unit	83.72^{b}	86.98^{ab}	86.10^{ab}	86.61^{ab}	90.46^{a}	0.75	0.040	0.048
Lipase, Sigma-Tietz unit	21.26	21.29	20.42	20.45	20.60	0.18	0.658	0.895
Amylase, Somogyi unit	26.35^{b}	28.34^{ab}	30.03^{ab}	29.47^{ab}	31.84^{a}	0.70	0.386	0.498
Jejunum 空肠								
Protease, unit	67.42^{b}	69.37^{ab}	71.88^{ab}	72.63^{ab}	74.03^{a}	0.84	0.330	0.623
Lipase, Sigma-Tietz unit	17.37	17.74	18.21	17.53	19.17	0.35	0.412	0.367
Amylase, Somogyi unit	13.83^{c}	13.86^{c}	15.74^{b}	16.31^{ab}	17.32^{a}	0.30	0.006	0.023

肠道

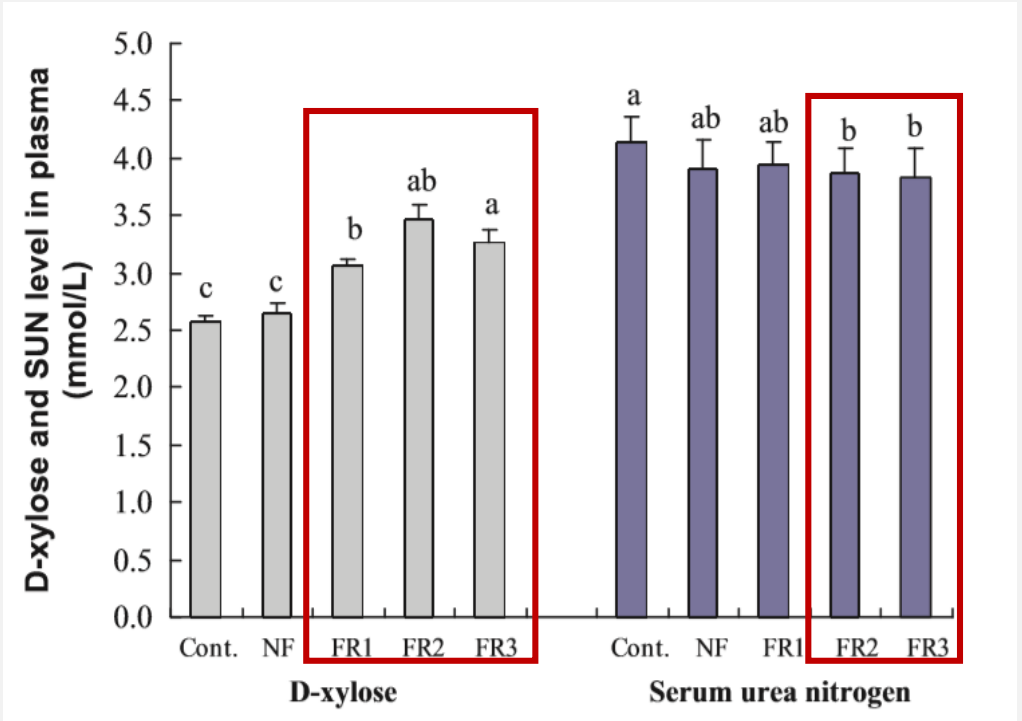
Fig. 2. 发酵银杏叶对42 d龄肉鸡十二指肠SGLT1表达的影响。



SGLT1-肠葡萄糖同化的主要介质

血浆

Fig. 3. 发酵银杏叶对42 d肉鸡血浆D-木糖和尿素氮水平的影响。



消化吸收能力增强，膳食氮利用率升高

总结

感谢大家的聆听，敬请批评指正！