单宁是影响高粱生长猪消化代谢能及其预测方程的关键因子

Tannin is a key factor in the determination and prediction of energy content in sorghum grains fed to growing pigs

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1. 前言 Introduction
2. 材料和方法 Material and Methods
3. 结果和讨论 Results and Discussion
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前 言
Introduction

前言 Introduction

- 第5大谷物作物，全球年产量6000多万吨

  The fifth commonly grown cereal grain, more than 63 million ton per year worldwide


小麦 wheat


水稻 rice

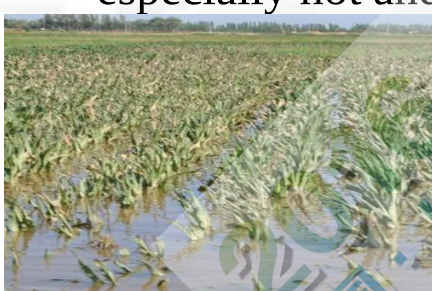

玉米 corn


大麦 barley


高粱 sorghum

- 耐逆性较强，种植区域广泛，尤其热带和干旱地区

  Strong stress tolerance, grow under a wider range of environmental conditions, especially hot and dry climate


洪涝 Flood


干旱 Drought


盐碱 Saline soil


贫瘠 barren soils

(Miller et al., 1964; Swick, 2011; FAO, 2015)

前言 Introduction

全球变暖
Global Warming

高粱 Sorghum

食物 Food

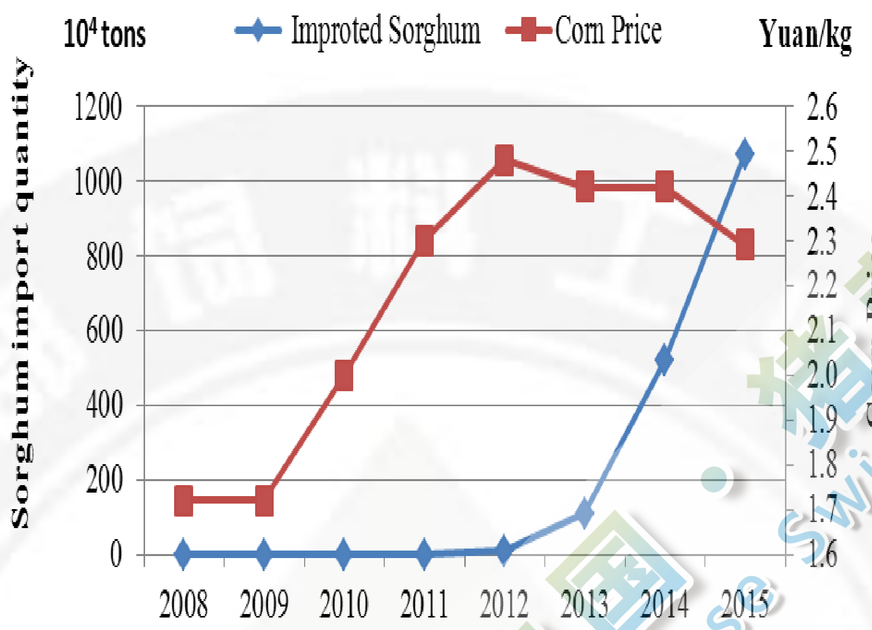
粮储降低
Declining Grain Inventory

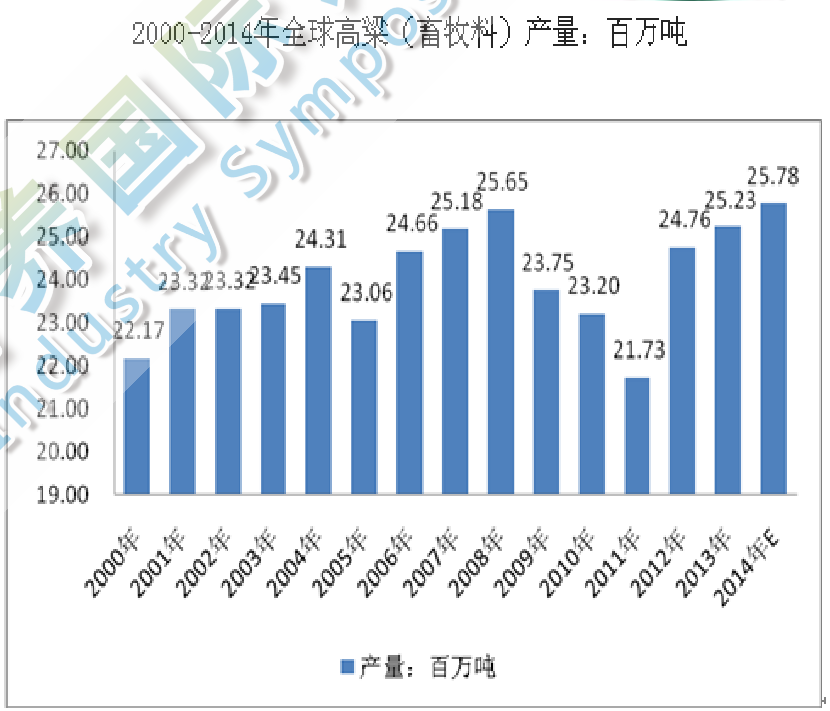
饲料 Feed

- 全球气候变暖以及粮食存储减少，高粱必然会广泛做为人和动物的食材
  With global warming and the declining global grain inventory, it is imperative that sorghum is fully used as a food and feed resource for humans and animals

(Selle et al., 2010; Paulk et al., 2015)

前言 Introduction





➢ 养殖户通过使用高粱代替玉米做能量饲料降低饲养成本

Swine producers are using sorghum as an alternative energy resource to reduce diet cost

(Selle et al., 2010; Paulk et al., 2015；FOA, 2015)

前言 Introduction

- 高粱抗性因子（单宁、醇溶蛋白等）导致营养价值相对较低

  Sorghum may not always be comparable with corn or other cereals due to the anti-nutritional factors (tannin, prolamin, phytate)

- 高粱单宁与能值负相关，可以显著降低营养价值

  Tannin has a negative relationship with effective energy in sorghum, which greatly decreases the nutritional quality

(Jacob et al., 1997; Khoddami et al., 2015)

前言 Introduction

选育
selective breeding

- 高粱选育品种较多，但不同品种的有效能值比较研究较少

  Few studies have been conducted to determine and compare the DE and ME content in different sorghum cultivars

- 准确评价不同品种间高粱有效能才能经济高效地精准配制日粮

  Accurately evaluating the effective energy in different types of sorghum is necessary to formulate diets economically and effectively

(Cervantes- Pahm et al., 2014a,b; Lowell et al., 2015)

前言 Introduction

- 假设：低单宁高粱具有更高的消化代谢能，并且单宁是预测高粱有效能值的关键因子

  Hypothesis: low-tannin sorghum cultivars (LTS) have a greater DE and ME content than high-tannin cultivars (HTS); and tannin could be a primary predictor for the effective energy

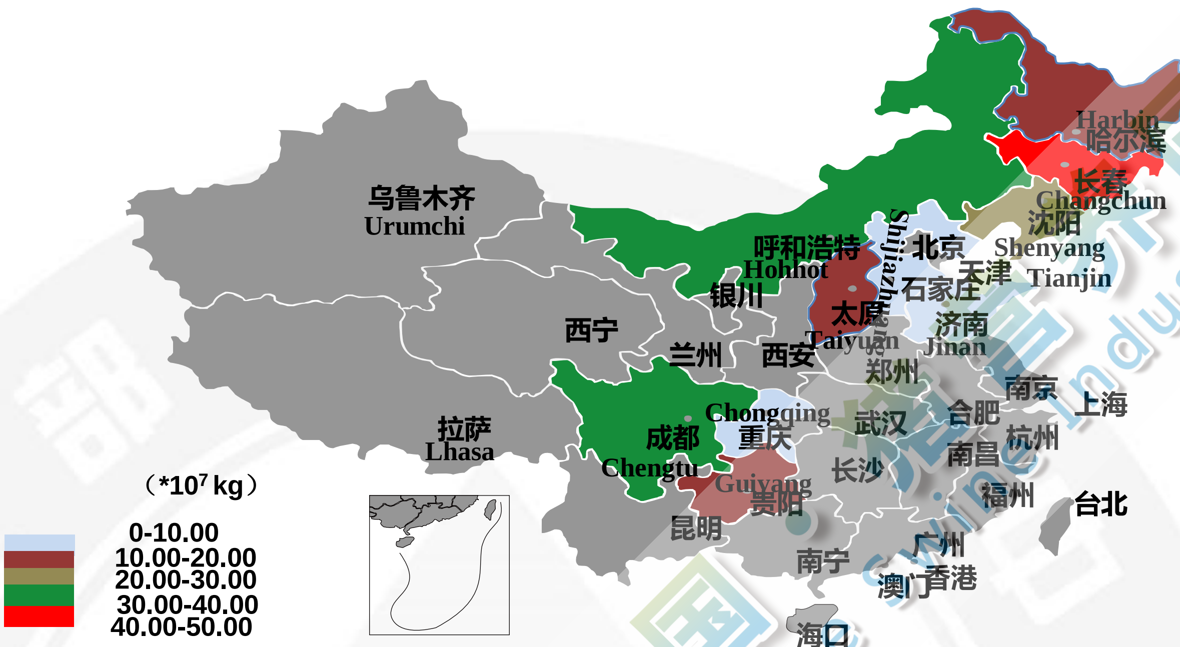
- 目的：测定并比较28种不同高粱品种的消化代谢能，并建立动态预测方程

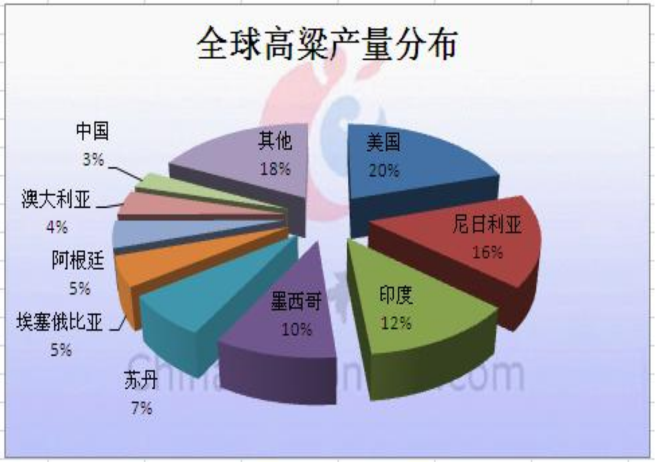
  Objective: to determine and compare the DE and ME content in 28 samples of sorghum grain; and to generate prediction equations for DE and ME based on chemical analysis

材料与方法
Materials and Methods

材料与方法 Materials and Methods

高粱样品采集 Collection of Sorghum Samples





- 采集国内9个省份25个高粱样品，并且购买美国和澳大利亚3个样品；

  A total of 25 sorghum samples were obtained from 9 provinces in China; and 3 sorghum samples were purchased from the United States and Australia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国家高粱改良中心

Table 1. Sources and physical characteristics of sorghum cultivars used in the experiment

No.	Source 来源			Physical characteristic 物理特性		
	City 城市	Province 省份	Country 国家	Color 颜色	Bulk weight (g/L) 容重	Thousand kernel weight (g) 千粒重
Low tannin cultivars 低单宁品种						
1	Chengde 承德	Hebei 河北	China 中	White 白	787	34.11
2	Shenyang 沈阳	Liaoning 辽宁	China	White	696	31.03
3	-	-	USA 美	Brown 棕	741	28.01
4	-	-	Australia 澳	Brown	793	35.81
5	Haerbin 哈尔滨	Heilongjiang黑龙江	China	White	621	19.33
6	Fuyu 扶余	Jilin 吉林	China	White	684	29.63
7	Jinzhou 锦州	Liaoning	China	White	777	34.02
8	-	-	Australia	Red 红	787	36.88
Medium tannin cultivars 中单宁品种						
9	Shenyang	Liaoning	China	Red	788	33.00
10	Binhai 滨海新区	Tianjin 天津	China	Brown	772	28.07
11	Jinzhou 锦州	Liaoning	China	Red	725	23.81
12	Jinzhong 晋中	Shanxi 山西	China	Red	761	30.27
13	Luzhou 泸州	Sichuan 四川	China	Red	702	32.64
14	Haerbin 哈尔滨	Heilongjiang	China	Red	654	22.39
15	Jinzhong 晋中	Shanxi	China	Brown	714	27.80
16	Jinzhong 晋中	Shanxi	China	Brown	781	33.39
17	Jinzhong 晋中	Shanxi	China	Black 黑	745	29.07
18	Shenyang 沈阳	Liaoning	China	Red	733	31.26
High tannin cultivars 高单宁品种						
19	Binhai 滨海	Tianjin	China	Brown	691	26.88
20	Binzhou 滨州	Shandong 山东	China	Brown	643	28.12
21	Binzhou 滨州	Shandong	China	Red	714	19.49
22	Jinzhong 晋中	Shanxi	China	Red	706	24.58
23	Mianyang 绵阳	Sichuan	China	Red	729	20.75
24	Binzhou 滨州	Shandong	China	Red	701	22.87
25	Fuyu 扶余	Jilin	China	Red	661	27.89
26	Tongliao 通辽	Inner Mongolia蒙	China	Red	733	27.31
27	Jinzhong 晋中	Shanxi	China	Black	704	38.58
28	Chifeng 赤峰	Inner Mongolia	China	Red	628	23.06

Table 2. Analyzed chemical composition of sorghum (DM basis)

No.	Tannin %	DM %	GE, kcal/kg	Chemical composition (%)							
				Starch	CP	EE	NDF	ADF	Ash	P	Ca
Low tannin cultivars 低单宁品种			总能	淀粉	粗蛋白	粗脂肪	中洗纤维	酸洗纤维	粗灰分	磷	钙
1	0.02	87.92	4391	70.30	11.91	1.57	15.52	4.27	2.00	0.37	0.05
2	0.04	88.29	4435	72.71	10.90	2.63	13.74	4.14	1.95	0.35	0.08
3	0.05	87.63	4389	77.00	9.01	2.07	11.98	3.49	1.52	0.30	0.02
4	0.06	89.03	4428	71.49	10.70	2.70	13.74	3.40	1.46	0.27	0.02
5	0.07	87.94	4423	70.36	11.00	0.78	16.88	4.31	1.99	0.34	0.24
6	0.08	86.40	4364	76.73	8.26	2.76	12.48	3.69	1.98	0.30	0.09
7	0.12	87.53	4438	73.21	11.71	2.52	12.45	3.26	1.58	0.32	0.04
8	0.16	88.53	4412	71.05	10.93	2.59	14.04	3.71	1.59	0.30	0.04
Mean	0.08	87.91	4410	72.85	10.55	2.20	13.85	3.78	1.76	0.32	0.07
SD	0.04	0.73	24.59	2.51	1.19	0.65	1.56	0.38	0.22	0.03	0.07
Medium tannin cultivars 中单宁品种											
9	0.67	88.71	4400	74.83	8.83	2.45	14.59	4.26	1.65	0.26	0.03
10	0.72	87.65	4455	69.72	11.20	3.08	17.10	4.99	1.77	0.32	0.03
11	0.79	87.55	4461	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.31	0.09
12	0.82	88.92	4391	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.27	0.06
13	0.85	84.91	4467	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.34	0.04
14	0.85	85.45	4403	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.31	0.05
15	0.88	88.79	4446	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.31	0.09
16	0.91	88.38	4445	[illegible]	[illegible]	[illegible]	[illegible]	4.24	[illegible]	0.25	0.09
17	0.93	88.74	4479	69.14	10.16	3.15	13.76	4.55	1.57	0.28	0.07
18	0.98	88.02	4440	68.47	10.54	2.90	15.66	4.92	2.07	0.36	0.05
Mean	0.84	87.71	4439	70.41	10.42	2.79	14.44	4.71	1.71	0.30	0.06
SD	0.09	1.35	28.66	2.14	1.26	0.49	1.60	0.52	0.20	0.03	0.02
High tannin cultivars 高单宁品种											
19	1.11	87.87	4484	66.12	11.40	3.67	16.49	5.70	2.57	0.31	0.05
20	1.12	89.15	4446	63.65	13.41	2.78	15.97	5.78	2.91	0.34	0.11
21	1.15	89.17	4453	68.98	10.66	3.41	14.05	4.16	2.54	0.26	0.26
22	1.21	89.04	4445	69.20	9.51	2.04	14.63	5.17	1.77	0.28	0.03
23	1.28	85.46	4447	69.93	10.22	2.83	11.99	3.97	1.78	0.32	0.04
24	1.28	88.56	4460	68.67	10.23	2.72	14.97	5.32	2.17	0.30	0.10
25	1.35	87.45	4471	64.11	12.53	2.79	15.96	5.13	2.43	0.40	0.04
26	1.41	87.08	4383	71.49	8.58	1.81	14.82	4.60	1.84	0.14	0.07
27	1.46	87.21	4496	65.65	12.26	3.09	15.73	5.08	1.83	0.37	0.03
28	1.51	87.78	4429	68.23	10.35	1.97	14.11	4.78	1.61	0.14	0.08
Mean	1.29	87.88	4452	67.60	10.92	2.71	14.87	4.97	2.15	0.29	0.08
SD	0.13	1.11	29.52	2.46	1.40	0.58	1.24	0.57	0.42	0.08	0.07

- 高粱单宁变化较大，分成3种类型
  Tannin content varied in a large range, 28 samples were divided into 3 classes

材料与方法 Materials and Methods

- **日粮：** 高粱谷粒通过锤片式粉碎过2毫米筛孔

Diet: All grains were ground in a hammer mill using a 2-mm screen





Table 3. Ingredient composition of the experimental diets (as-fed basis, %)

Ingredient	成分	Diet 日粮
Sorghum	高粱	96.9
Dicalcium phosphae	磷酸氢钙	1.7
Limestone	石粉	0.6
Sodium chloride	食盐	0.3
Vitamin and mineral premix	预混料	0.5

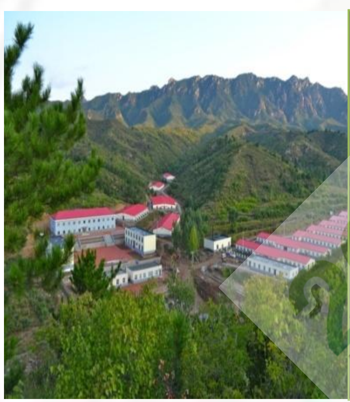
材料与方法 Materials and Methods

- **猪：** 84头公猪（36.5±3.4和41.3±3.9 kg）单独饲养于代谢笼

  Pigs: 84 barrows (BW: 36.5±3.4 and 41.3±3.9 kg for 1^{st} and 2^{nd} period) were individually housed in stainless-steel metabolic crates

- **设计：** 28种日粮随机分给3头猪，持续2期；每期适应7天，采集随后5天全部粪尿，每天按照体重4%饲喂量分两顿饲喂

  Design: 28 diets were randomly fed to 3 barrows in each period for 6 replicates/diet in 2 consecutive periods. Each period included a 7-d adaptation followed by a 5-d total collection of feces and urine. Pigs were fed an amount of feed equivalent to 4% of their BW each day





结果与讨论

Results and Discussion

结果与讨论 Results and Discussion

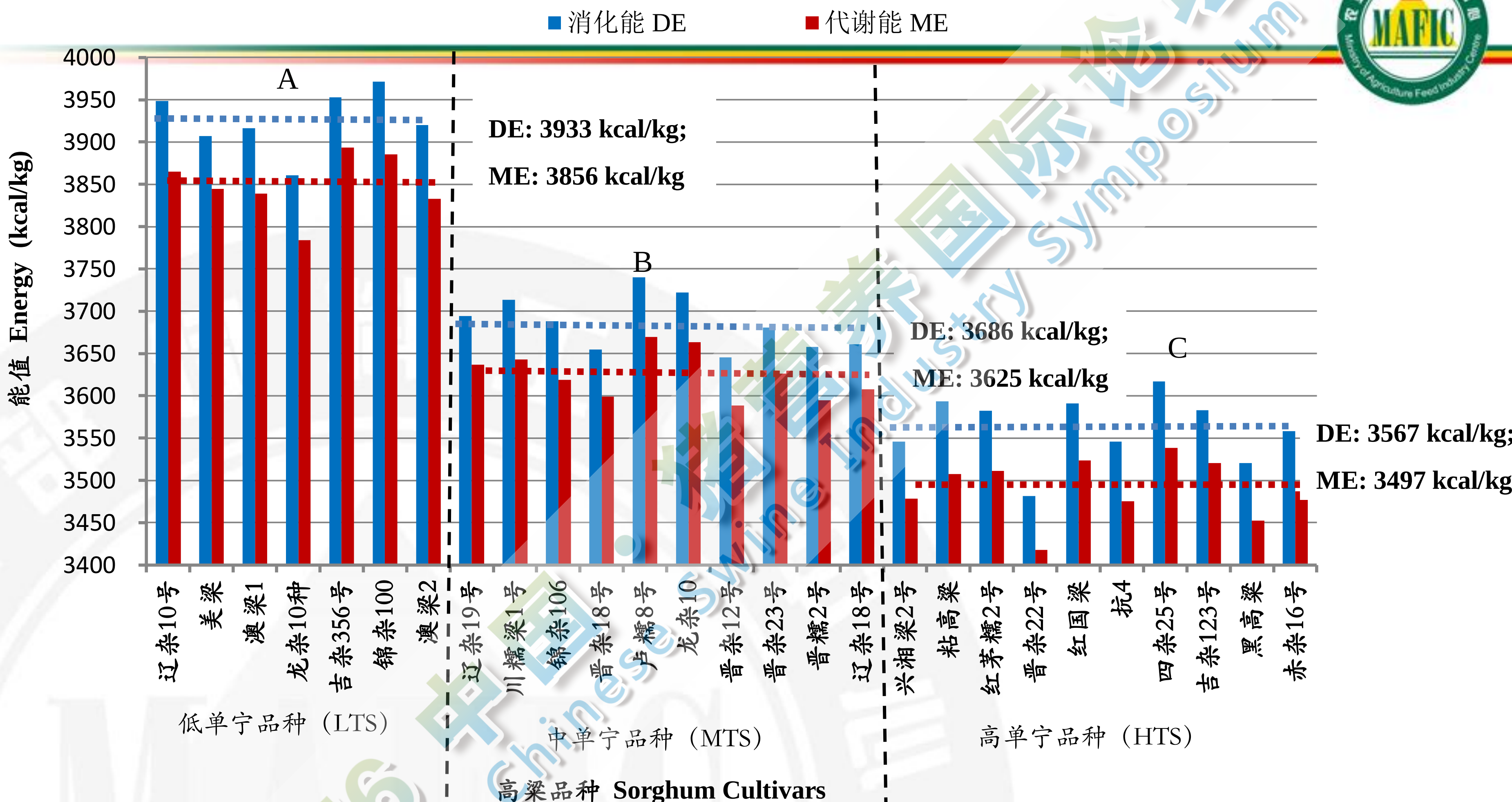


图 1. 不同高粱品种的消化能和代谢能（干物质）

Fig. 1. Digestible and metabolizable energy in sorghum cultivars (DM basis)

- DE（3520-3980 kcal/kg）和ME（3418-3905 kcal/kg）变异大；有效能：LHS>MTS>HTS
  Substantial variation; Mean DE and ME: LHS>MTS>HTS

结果与讨论 Results and Discussion

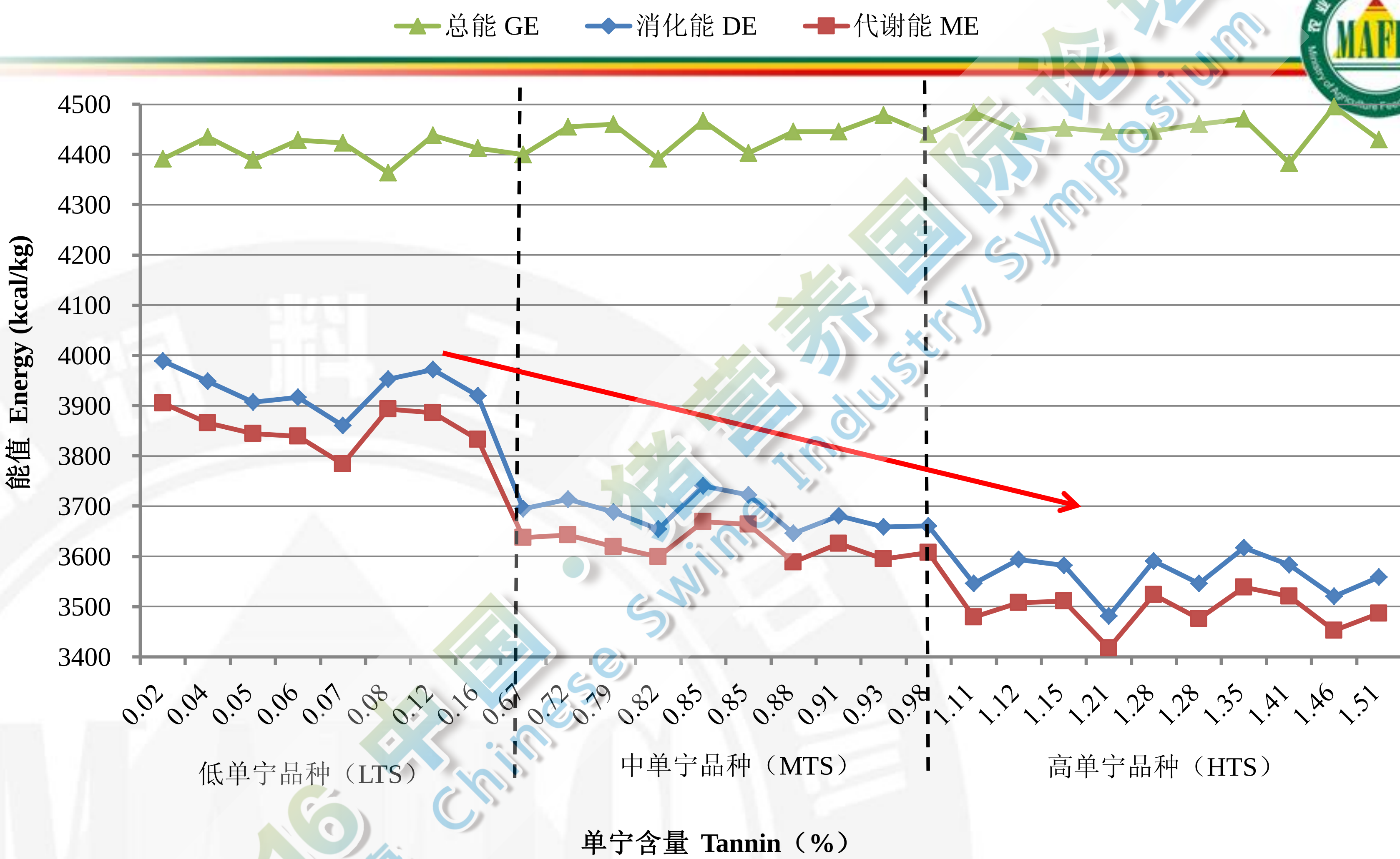


图 2. 能值随着单宁含量的变化

Fig. 2. Energy changes along with tannin content

结果与讨论 Results and Discussion

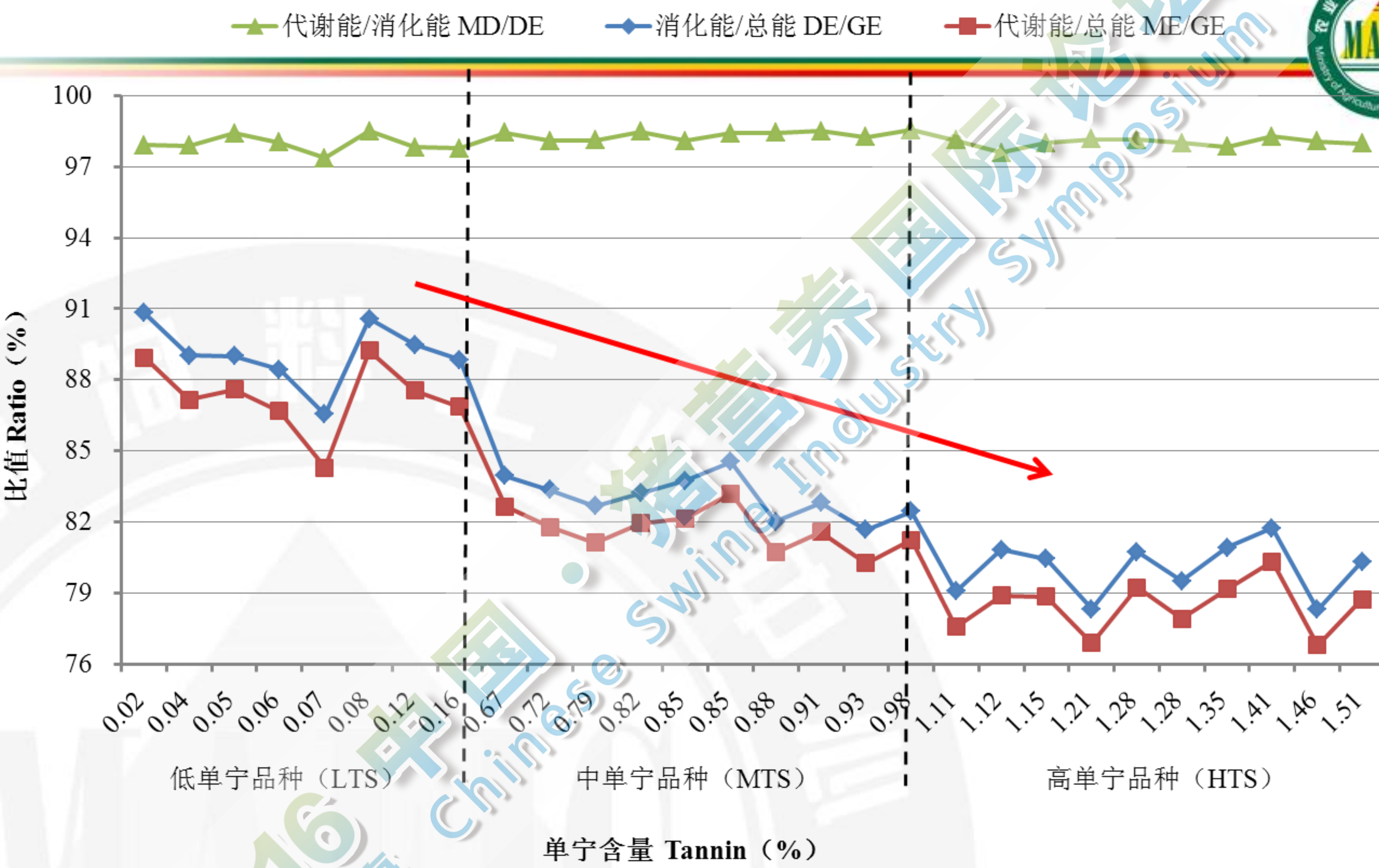


图3. 能值效率随着单宁含量的变化

Fig. 3. Energy efficiency changes along with tannin content

结果与讨论 Results and Discussion

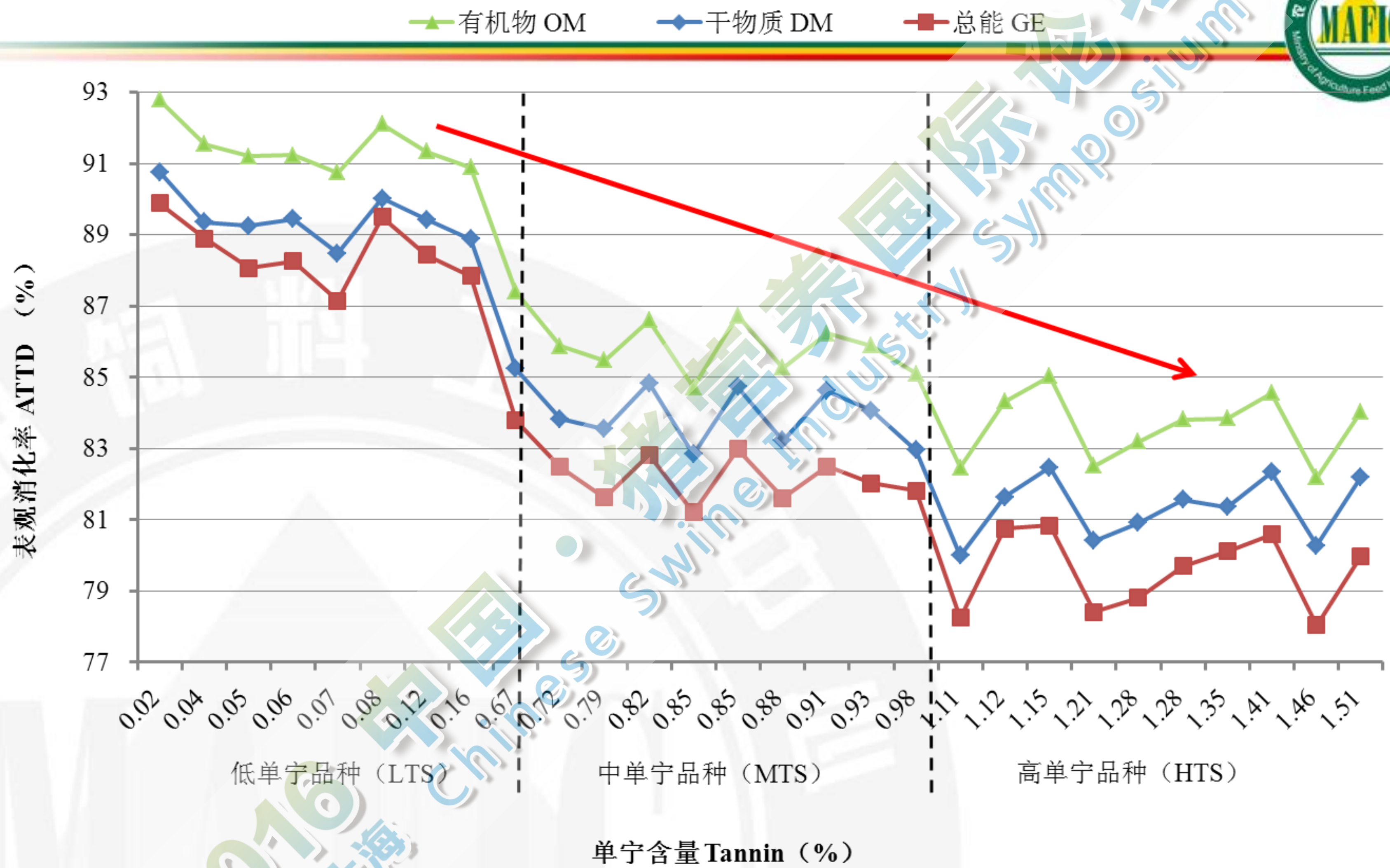


图4. 能量表观消化率随单宁含量的变化

Fig. 4. ATTD of energy changes along with tannin content

结果与讨论 Results and Discussion

表4. 高粱能值和化学成分的相关系数

Table 4. Correlation coefficients between chemical constituents and energy content (DM basis)

项目 Item	相关系数 correlation coefficient（R）							
	单宁 Tannin %	总能 GE kcal/kg	总淀粉 Starch %	粗蛋白 CP %	粗脂肪 EE %	中洗纤维 NDF %	酸洗纤维 ADF %	粗灰分 Ash %
消化能 DE, kcal/kg	-0.96**	-0.52**	0.61**	-0.03	-0.30	-0.27	-0.69**	-0.30
代谢能 ME, kcal/kg	-0.96**	-0.55**	0.65**	-0.07	-0.30	-0.30	-0.70**	-0.33
消化能/总能 DE/GE, %	-0.95**	-0.64**	0.68**	-0.13	-0.34	-0.33	-0.72**	-0.32
代谢能/总能 ME/GE, %	-0.94**	-0.65**	0.71**	-0.17	-0.32	-0.36	-0.73**	-0.35
总能消化率 ATTD of GE, %	-0.96**	-0.62**	0.68**	-0.14	-0.37	-0.31	-0.73**	-0.31
代谢能/消化能 ME/DE, %	0.15	-0.25	0.42*	-0.65**	0.30	-0.44*	-0.11	-0.41*

- 高粱消化代谢能与单宁含量高度负相关
  DE and ME have a high negative correlation with tannin

表 5 28种高粱消化代谢能的逐步回归方程

Table 5. Stepwise regression equations for DE and ME in 28 sorghum cultivars (DM basis)

Item	Regression coefficient 回归系数					Statistics 统计参数				
	Intercept	Tannin %	ADF %	CP %	GE kcal/kg	R^2	C(p)	RMSE	AIC	*P*-value
Equations for digestible energy (DE; kcal/kg)										
[1]	3944	-294				0.93	8.27	41.41	210	< 0.01
SE	14.62	15.80								
P-values	< 0.01	< 0.01								
[2]	4034	-272	-23.66			0.94	7.00	40.03	209	< 0.01
SE	55.69	20.00	14.09							
[3]	3959	-256	-44.48	14.80		0.95	3.92	37.11	206	< 0.01
SE	61.52	19.85	15.99	6.57						
[4]	6974	-236	-43.27	24.96	-0.71	0.96	1.64	34.35	203	< 0.01
SE	1347	20.49	14.81	7.58	0.32					
P-values	< 0.01	< 0.01	< 0.01	< 0.01	0.04					
Best equation: DE = 6974 – (236 × Tannin) – (43.27 × ADF) + (24.96 × CP) – (0.71 × GE)										
Equations for metabolizable energy (ME; kcal/kg)										
[5]	3869	-287				0.93	5.84	39.00	207	< 0.01
SE	13.77	14.88								
[6]	3973	-262	-27.24			0.94	3.32	36.64	204	< 0.01
SE	50.97	18.30	12.90							
P-values	< 0.01	< 0.01	0.04							
Best equation: ME = 3973 – (262 × Tannin) – (27.24 × ADF)										

- 首要预测因子是单宁，次要预测因子是酸洗纤维；
  Initial variable: tannin; Secondary variable: ADF;

表 5 28种高粱消化代谢能的逐步回归方程（续）

Table 5. Stepwise regression equations for DE and ME in 28 sorghum cultivars (DM basis，cont.)

Item	Regression coefficient 回归系数					Statistics 统计参数				
	Intercept	Tannin %	ADF %	CP %	GE kcal/kg	R^2	C(p)	RMSE	AIC	*P*-value
Equations for DE/GE (%)										
[7]	89.35	-7.81				0.90	24.5	1.22	12.84	< 0.01
SE	0.43	0.46								
P-values	< 0.01	< 0.01								
[10]	241.28	-5.21	-1.01	0.57	-0.03	0.96	1.64	34.35	203	< 0.01
SE	32.86	0.50	0.36	0.18	0.01					
P-values	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01					
Best equation: DE/GE = 241.28 – (5.21× Tannin) – (1.01× ADF) + (0.57 × CP) – (0.03 × GE)										
Equations for ME/GE (%)										
[11]	87.61	-7.00				0.89	25.8	1.27	15.48	< 0.01
SE	0.45	0.49								
P-values	< 0.01	< 0.01								
[14]	235.13	-5.09	-0.96	0.43	-0.03	0.95	4.56	0.91	-0.70	< 0.01
SE	35.74	0.54	0.39	0.20	0.01					
P-values	< 0.01	< 0.01	0.02	0.04	<0.01					
Best equation: ME/GE = 235.13 – (5.09× Tannin) – (0.96× ADF) + (0.43× CP) – (0.03 × GE)										
Equations for ATTD of GE(%)										
[15]	88.71	-7.17				0.92	17.9	1.05	4.85	< 0.01
SE	0.37	0.40								
P-values	< 0.01	< 0.01								
[17]	163.15	-6.09	-0.59		-0.02	0.96	4.26	0.83	-6.44	< 0.01
SE	26.68	0.42	0.32		0.01					
P-values	< 0.01	< 0.01	0.08		0.01					
Best equation: ATTD of GE = 163.15 – (6.09 × Tannin) – (0.59 × ADF) – (0.02 × GE)										

结果与讨论 Results and Discussion

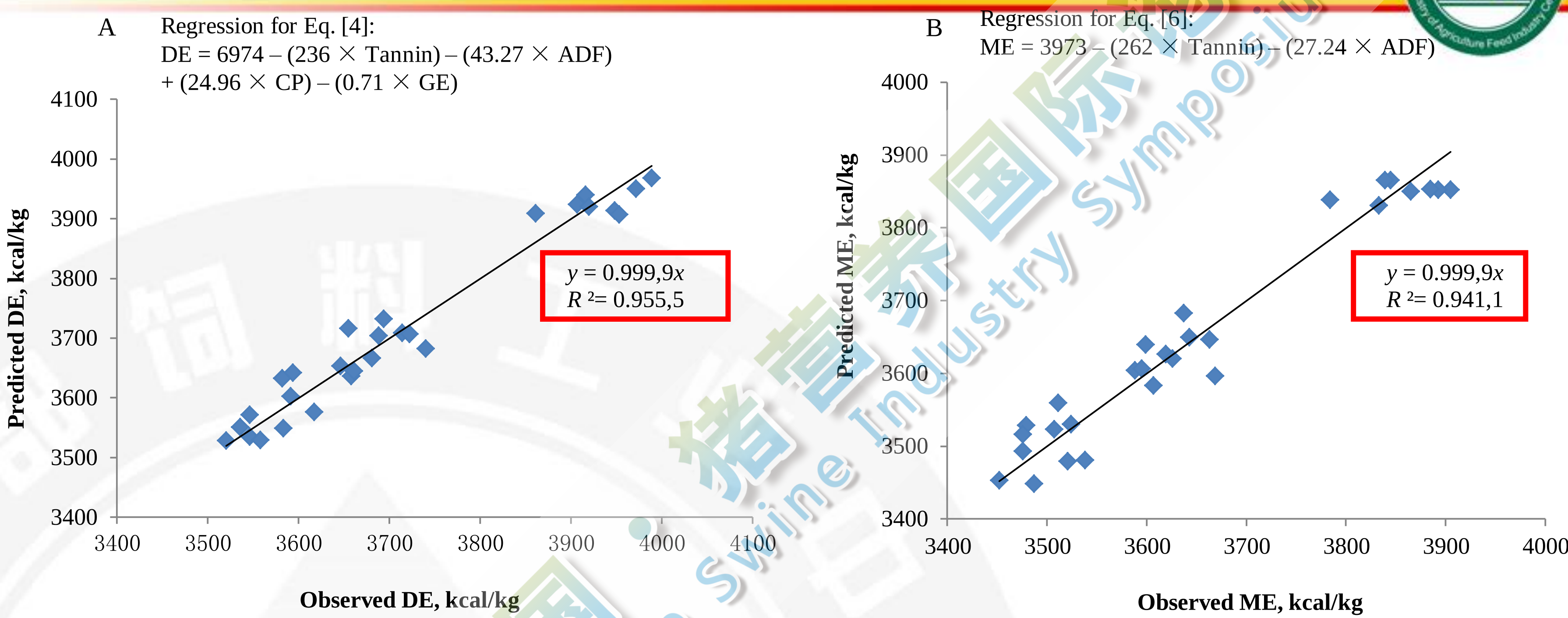


图5. 消化和代谢能最佳预测方程预测值和实测值的线性关系

Fig. 5. Relationships between predicted and observed values for DE using prediction Eq. [4] (A), and ME using prediction Eq. [6] (B)

- 线性斜率几乎为1，线性系数均高于0.94，预示着预测方程的准确性
  The slopes were almost 1, and the R^2 values were both more than 0.94, which indicates great accuracy in predicting DE and ME using best prediction equations

小结：高粱有效能动态方程

Summary: Prediction equation for energy

消化能预测方程 Prediction equation for DE：

- ✓ DE=3944-294×Tannin R^2=0.93
- ✓ DE=4034-272×Tannin-23.66×ADF R^2=0.94
- ✓ DE=3595-256×Tannin-44.48×ADF+14.80×CP R^2=0.95
- ✓ DE=6974-236×Tannin+43.27×ADF+24.96×CP – 0.71×GE R^2=0.96

代谢能预测方程 Prediction equation for ME：

- ✓ ME=0.97×DE R^2=0.99
- ✓ ME=3869-287×Tannin R^2=0.93
- ✓ ME=3973-262×Tannin-27.24×ADF R^2=0.9

能值效率最佳预测方程 Best prediction equation for energy efficiency：

- ✓ DE/GE=241.28-5.21×Tannin-1.01×ADF+0.57×CP-0.03×GE R^2=0.96
- ✓ ME/GE=235.13-5.09×Tannin-0.96×ADF+0.43×CP-0.03×GE R^2=0.95
- ✓ ATTD of GE=163.15-6.09×Tannin-0.59×ADF-0.02×GE R^2=0.96

➢ 单宁含量每增加1%，高粱消化代谢能降低200 kcal/kg以上，总能消化率降低6%以上

DE and ME could decrease by more than 200 kcal/kg and ATTD of GE decrease by more than 6% when the tannin is increased by 1%.

结论
Conclusion

结论 Conclusion

- **该28种高粱消化代谢能与化学成分尤其是单宁含量密切相关**
  The DE and ME content of sorghum grains (*n* = 28) are related to their chemical composition and especially to their tannin content;

- **高粱消化代谢能可通过化学成分准确预测；单宁含量每增加1% 消化代谢能降低200kcal/kg以上，总能消化率降低6%以上**
  The DE and ME for the 28 sorghum grains could be accurately and precisely predicted, and DE and ME was decreased more than 200 kcal/kg and ATTD of GE decrease by more than 6% when its tannin content was increased by 1%;

- **单宁是负面影响高粱消化代谢能关键预测因子，在高粱用作能量饲料时不得不考虑其中单宁的抗营养特性**
  Tannin is a key negative predictor for the DE and ME in sorghum grains, and the potent anti-nutritional properties of tannin should not be ignored when sorghum is used as an energy source for pigs.

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敬请批评指正

Thanks for your attention!

Comments are welcome!

高粱在断奶仔猪、生长育肥猪以及肉鸡上的应用研究

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