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Canada

Importance of Rumen Microbiology in Feed Digestion and Health of Ruminants

瘤胃微生物对饲料消化和瘤胃健康的重要性

Tim A. McAllister

**2019 - 4th National Symposium on
Applied Techniques and Industry
Economics in Beef Production**

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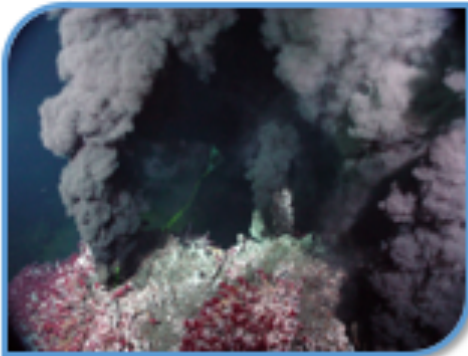
tim.mcallister@canada.ca

Mixi Övün Postrochla

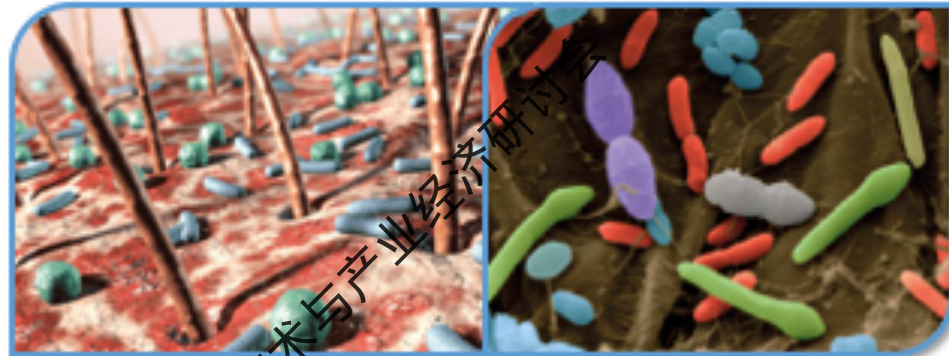
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Microbes are part of the natural world

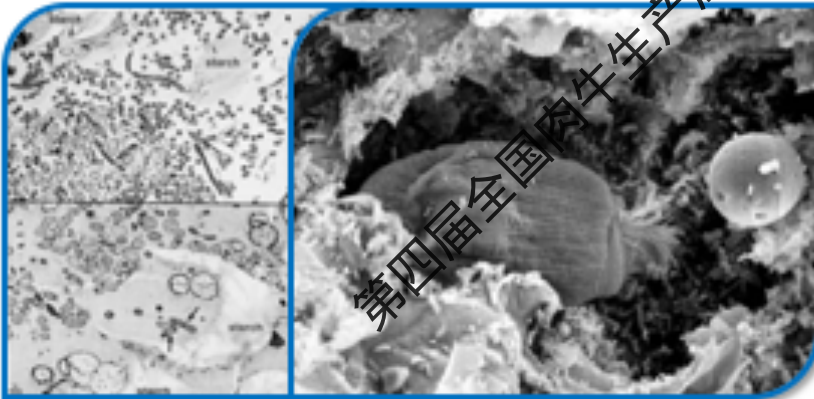
微生物是自然界的一部分



Deep sea vents
深海喷发口



On our skin and in our digestive tract
人体皮肤和消化道内



In the digestive tract of cattle
牛消化道内



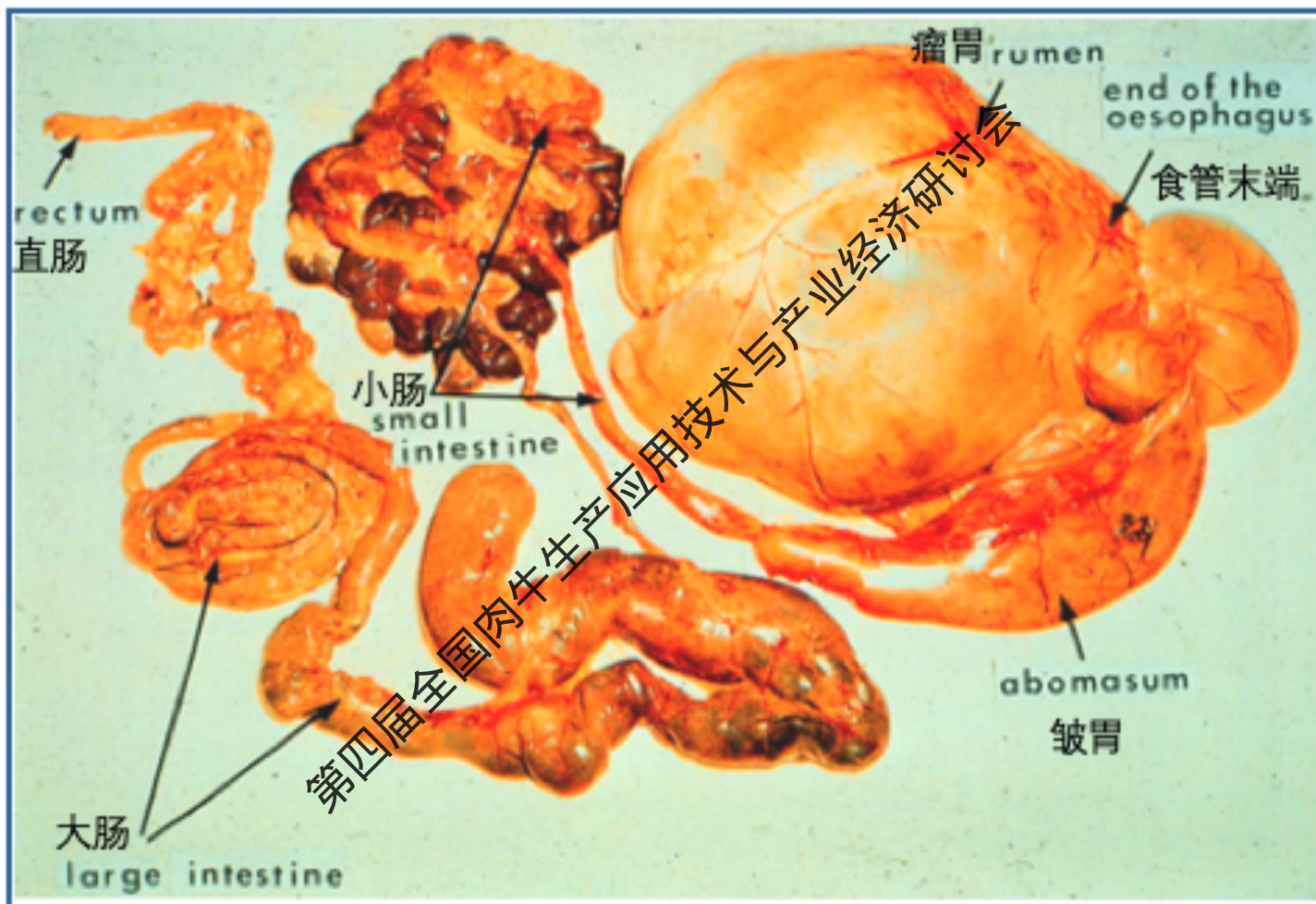
In our food
食物里

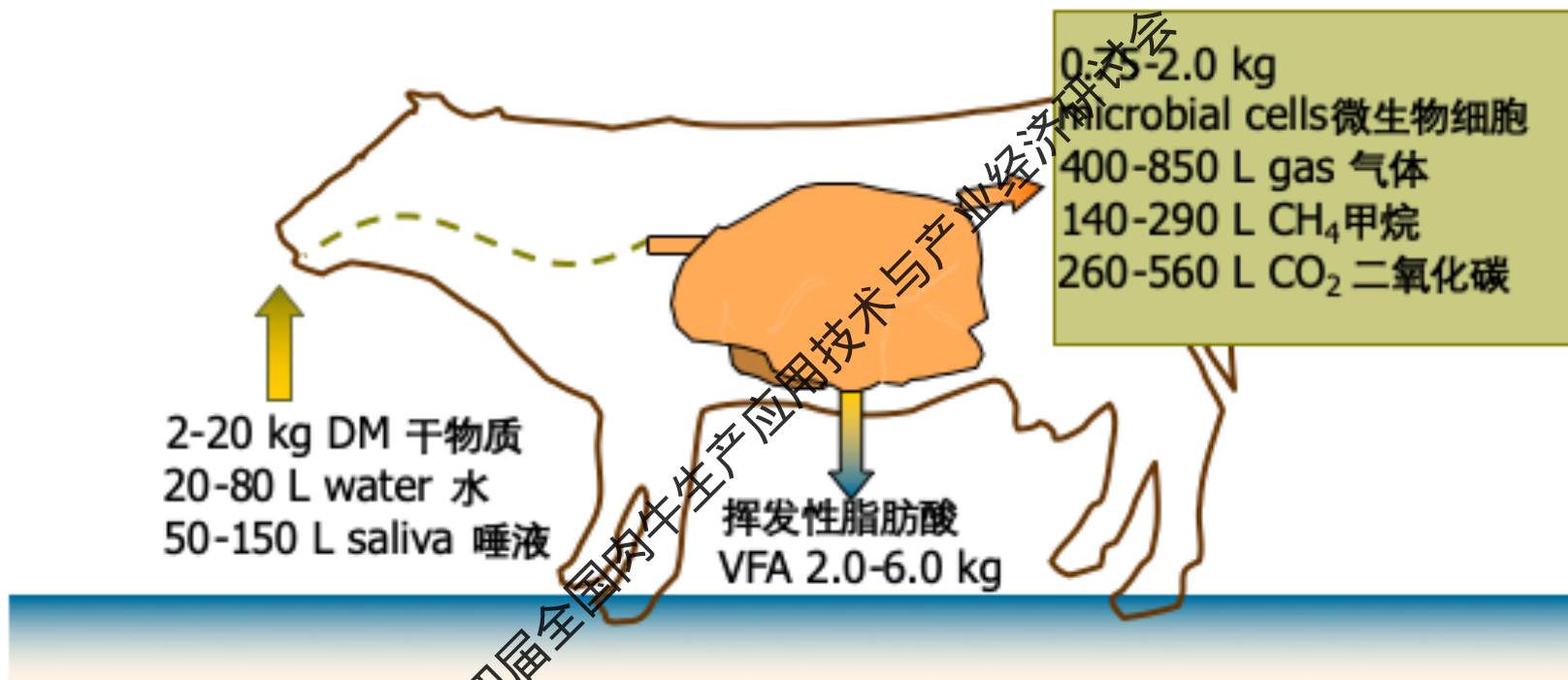
A window into the rumen microbiome

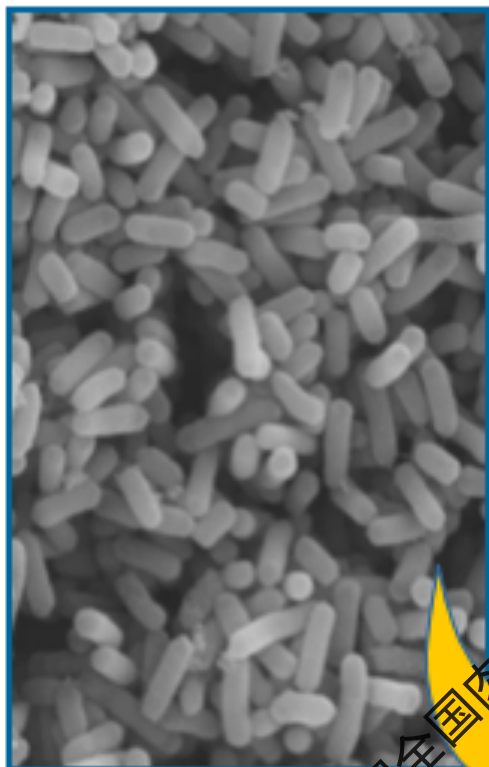
通向瘤胃微生物的一扇窗



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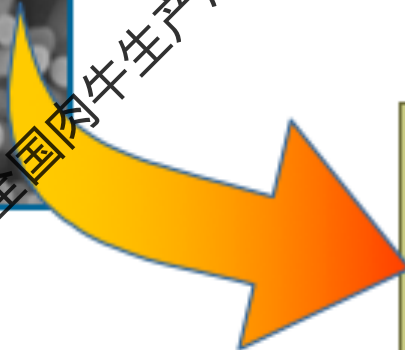




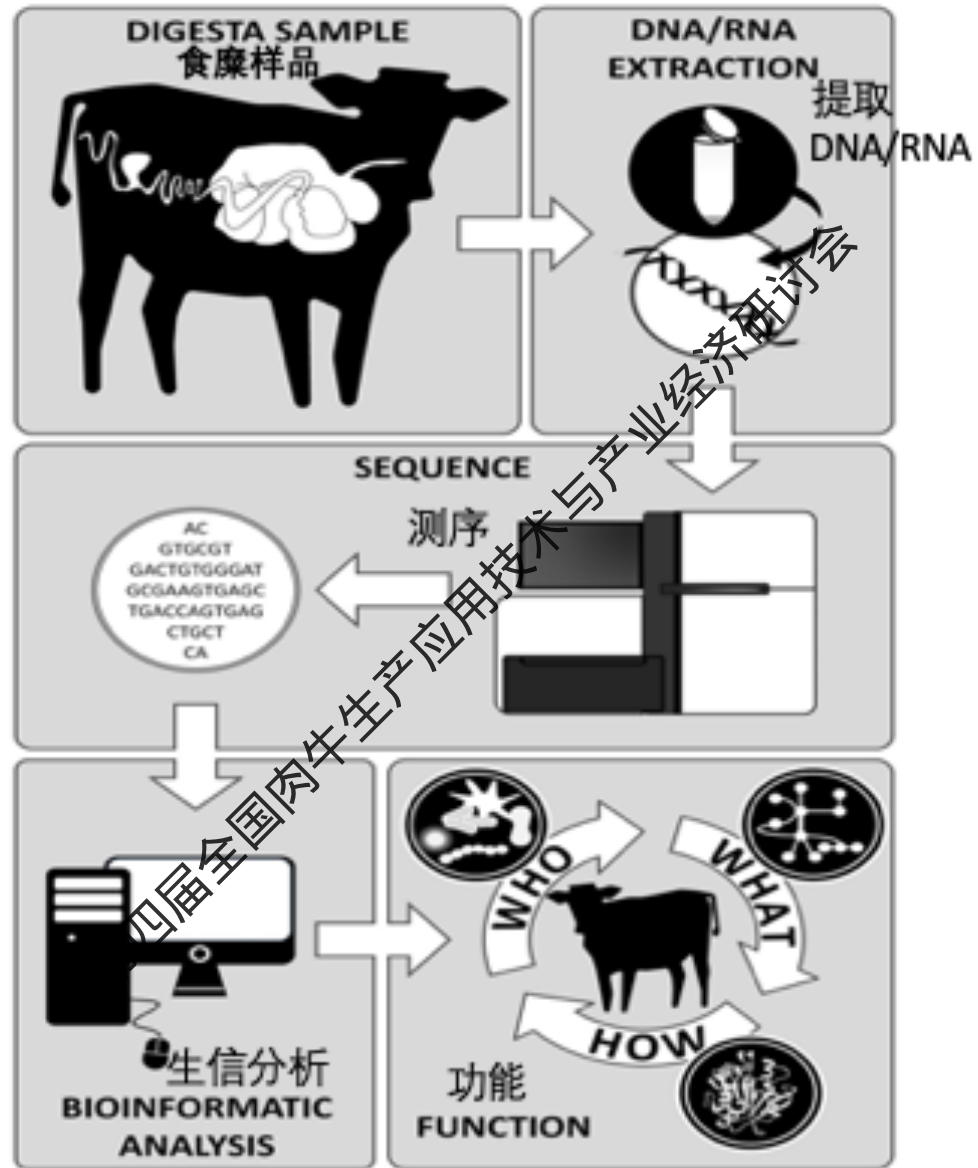


Acetate	乙酸	65
Propionate	丙酸	25
Butyrate	丁酸	10

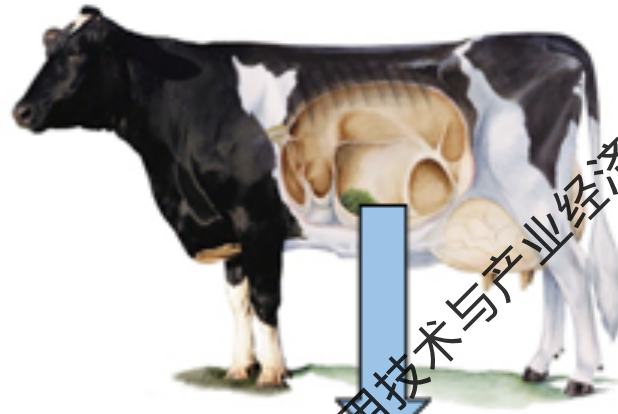
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Supply
70% energy
Requirements
满足70%的能量需求




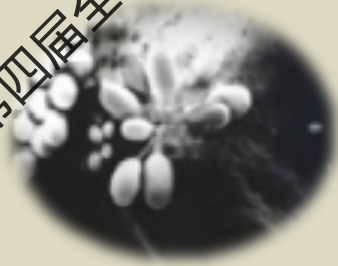


Rumen microbiome 瘤胃微生物



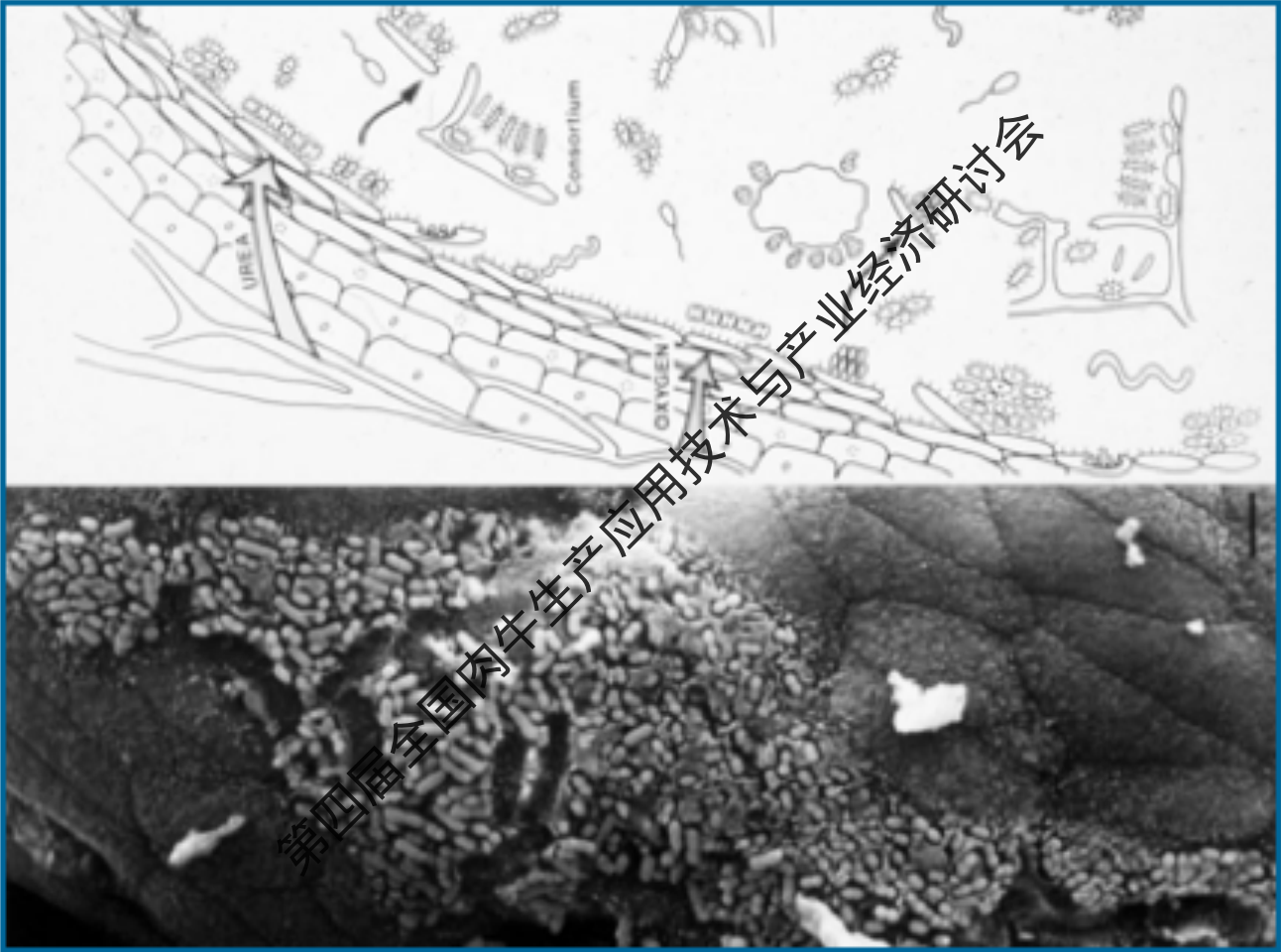
Redundant数量繁多

• **Resilient**可恢复

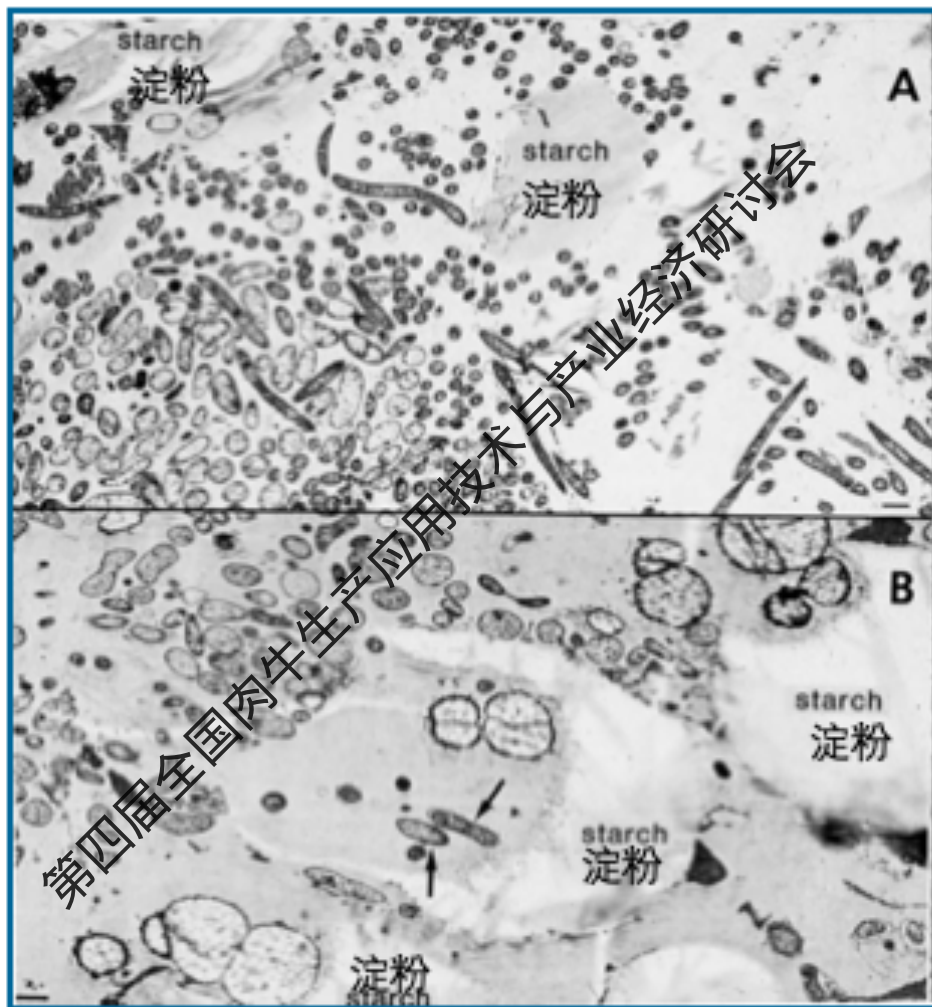
• **Stable**稳定

Bacteria 细菌	Anaerobic Fungi 厌氧真菌	Ciliate Protozoa 纤毛原虫	Methanogenic Archaea 产甲烷古菌
10^{10} to 10^{11} cells/ml 细胞/毫升	$<10^6$ cells/ml 细胞/毫升	$<10^5$ cells/ml 细胞/毫升	10^6 to 10^8 cells/ml 细胞/毫升
			

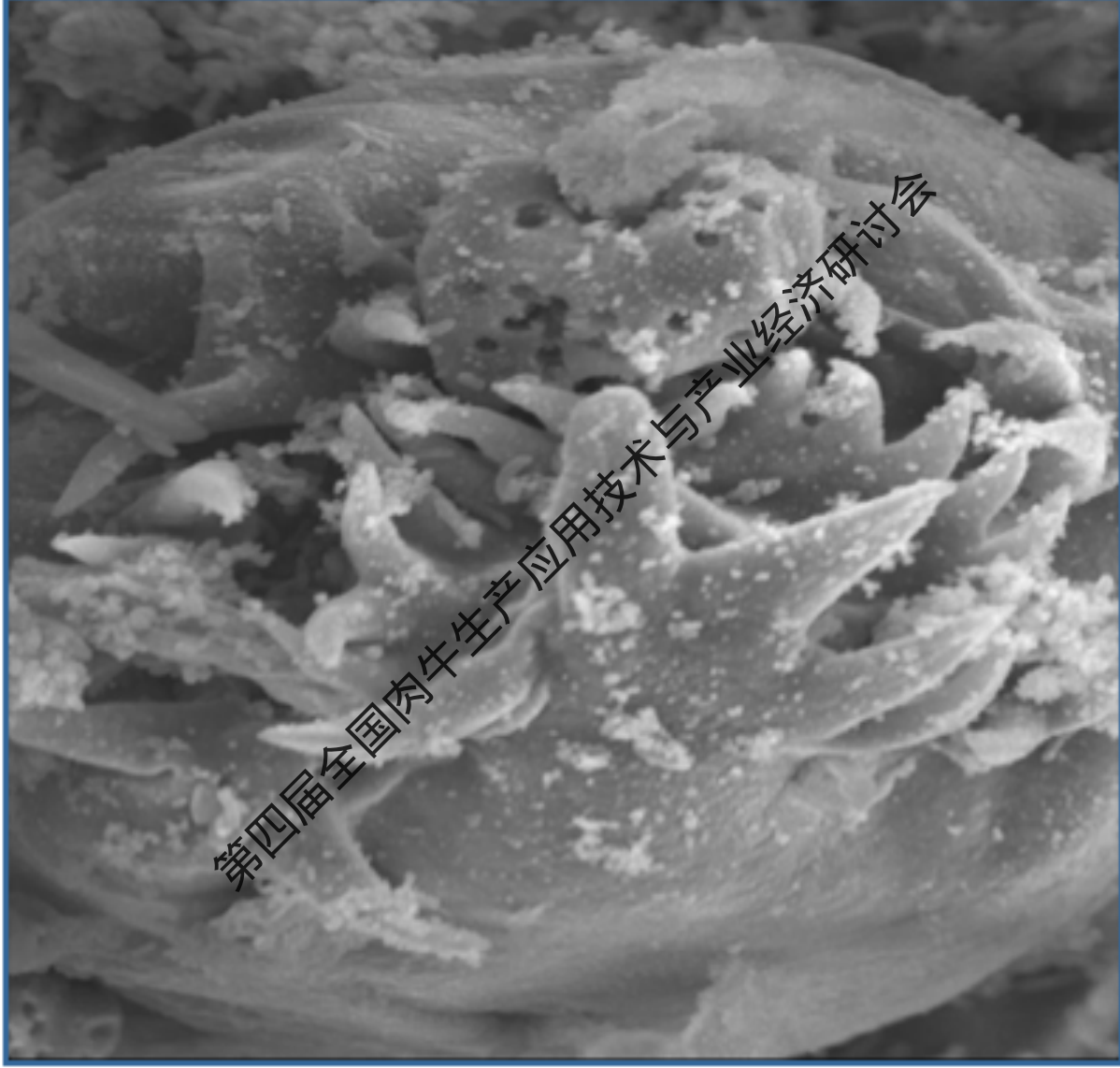
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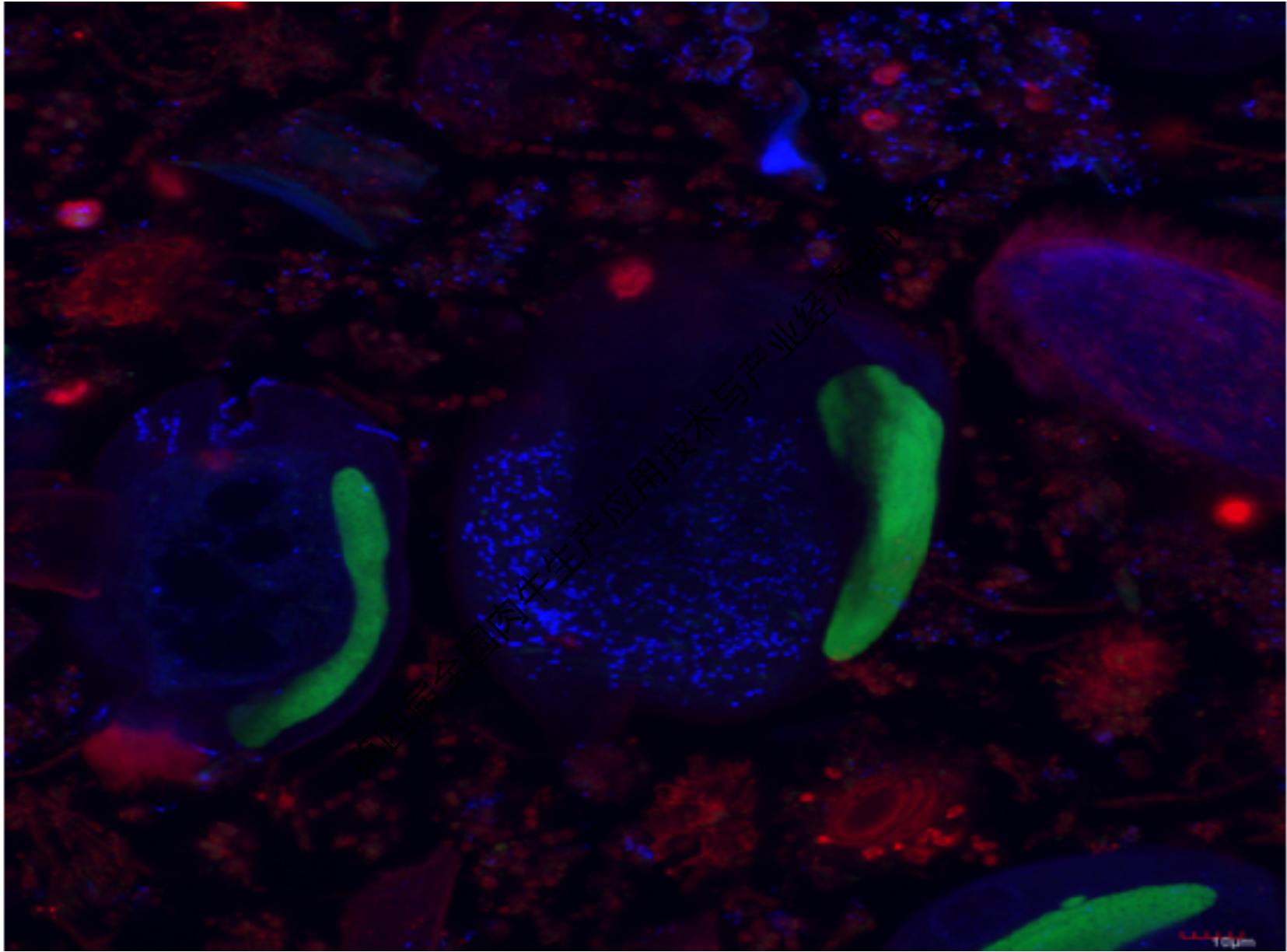
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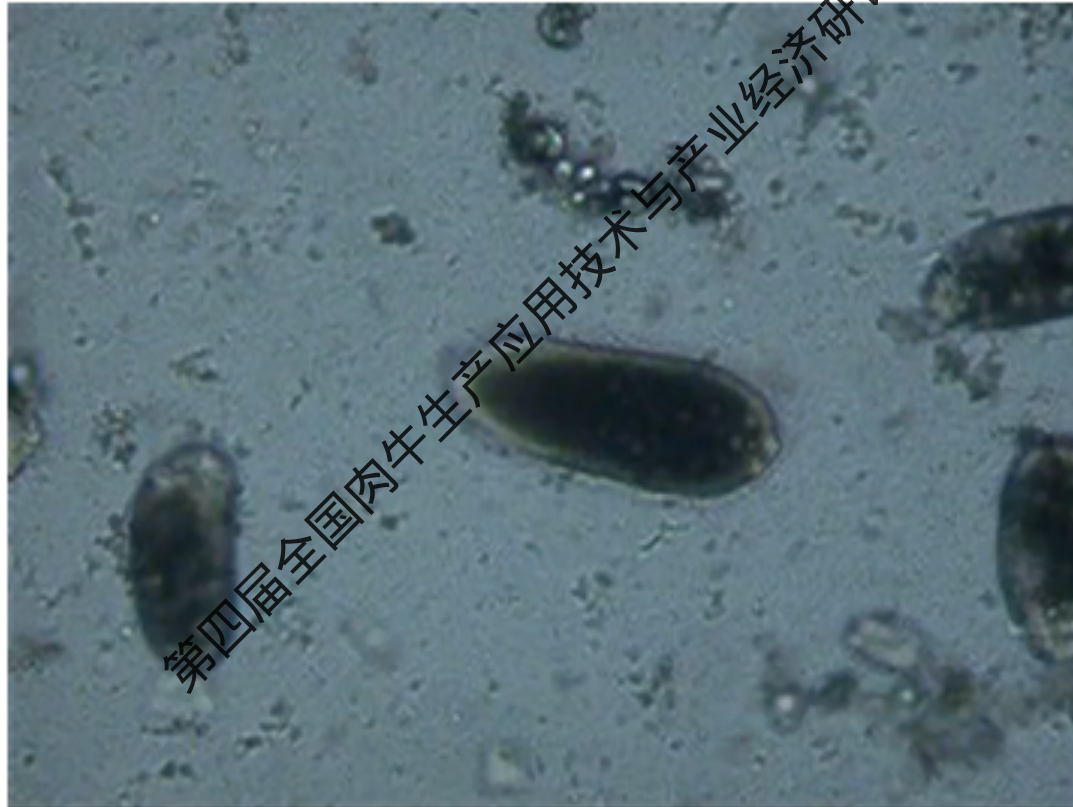
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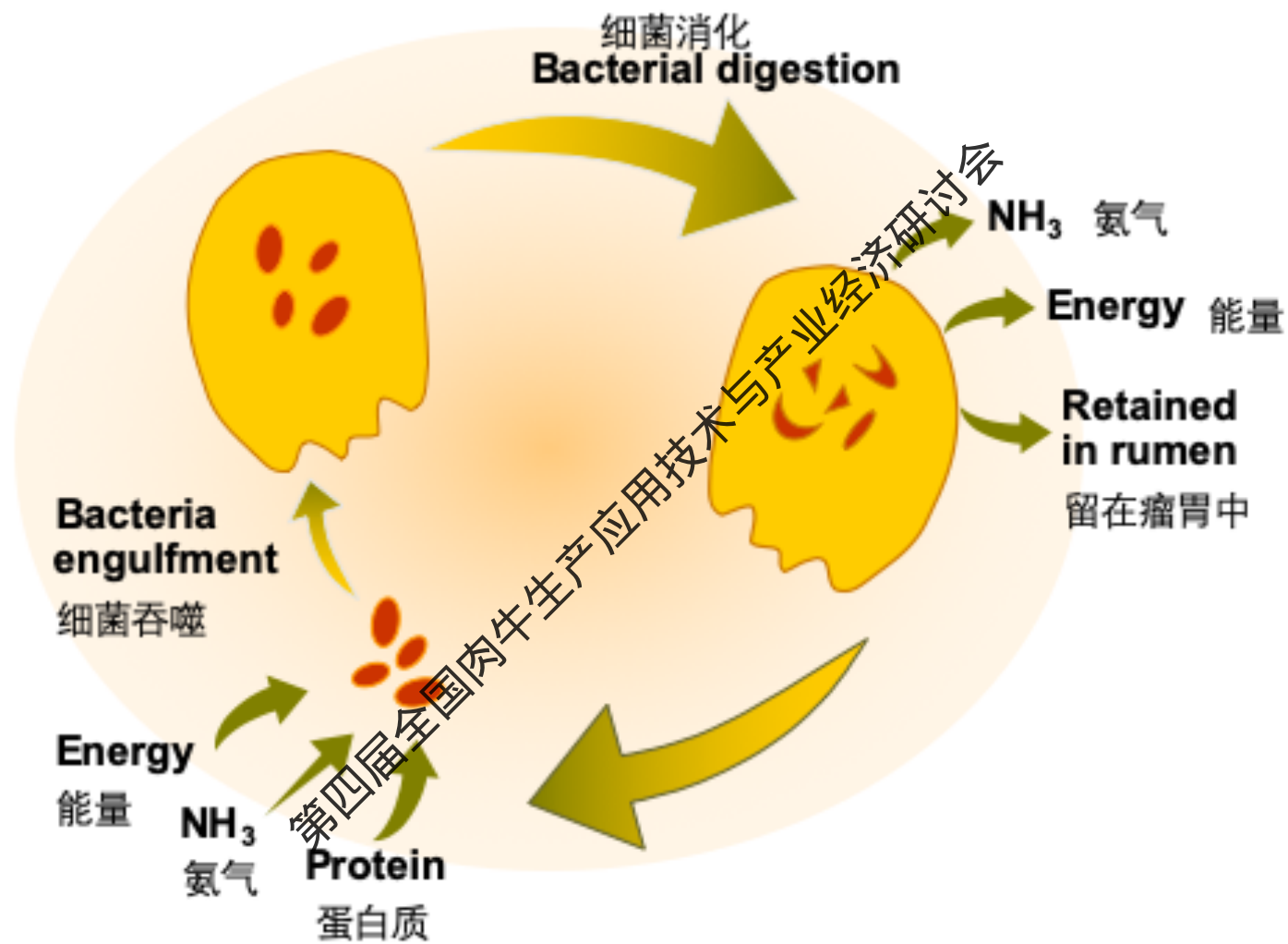


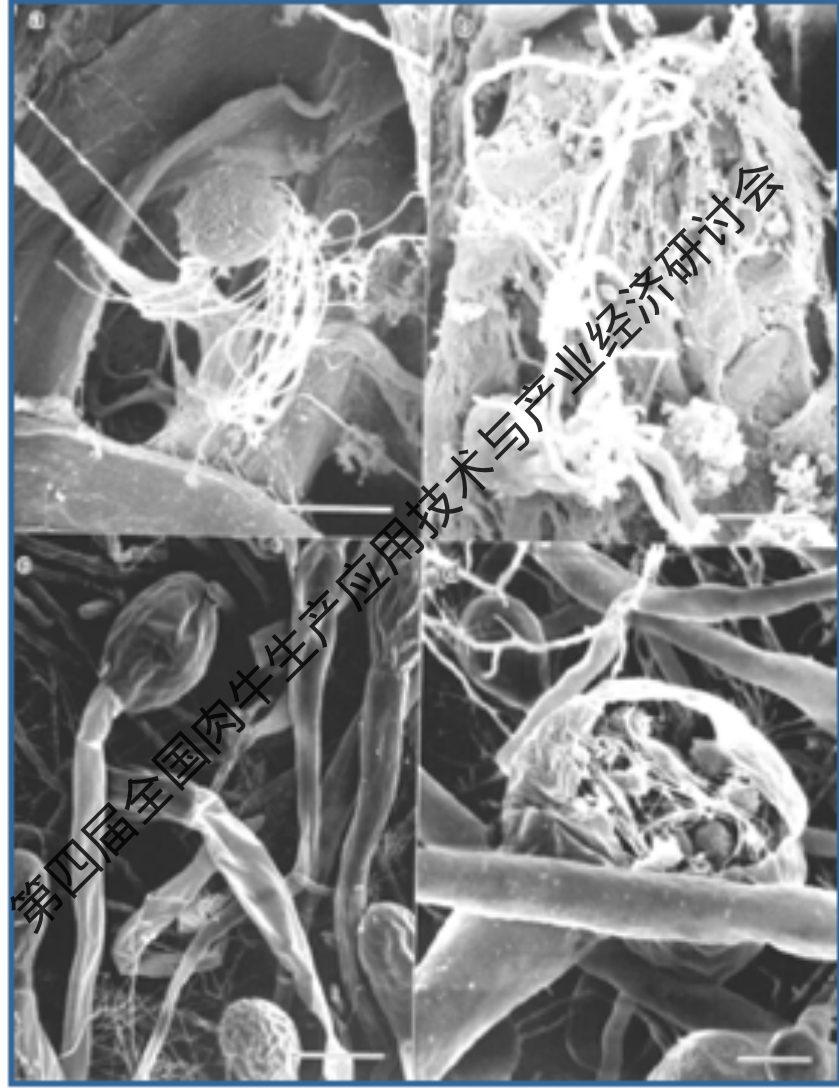
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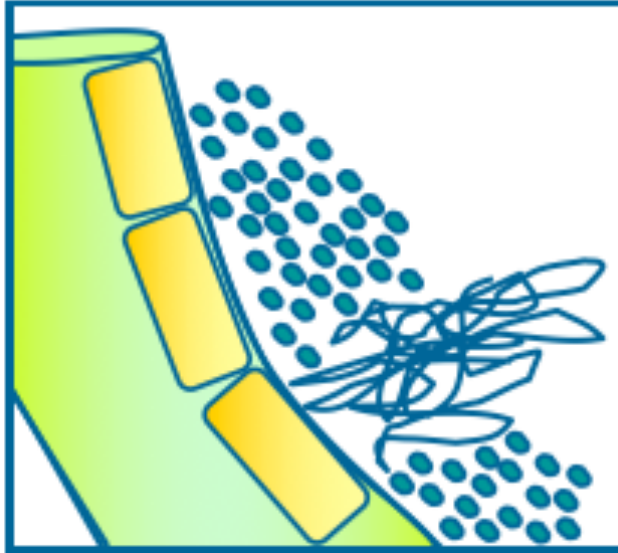
Rumen Protozoa Video

瘤胃原虫视频



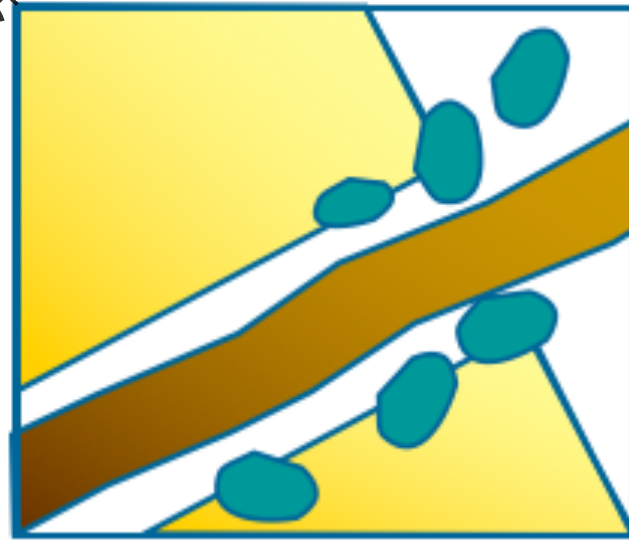
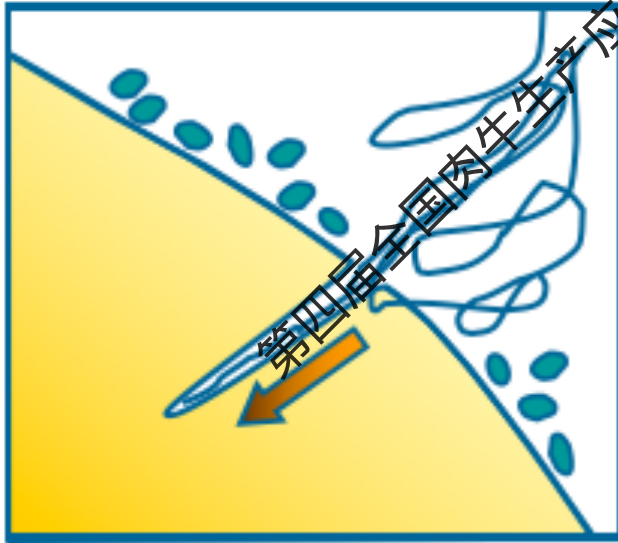




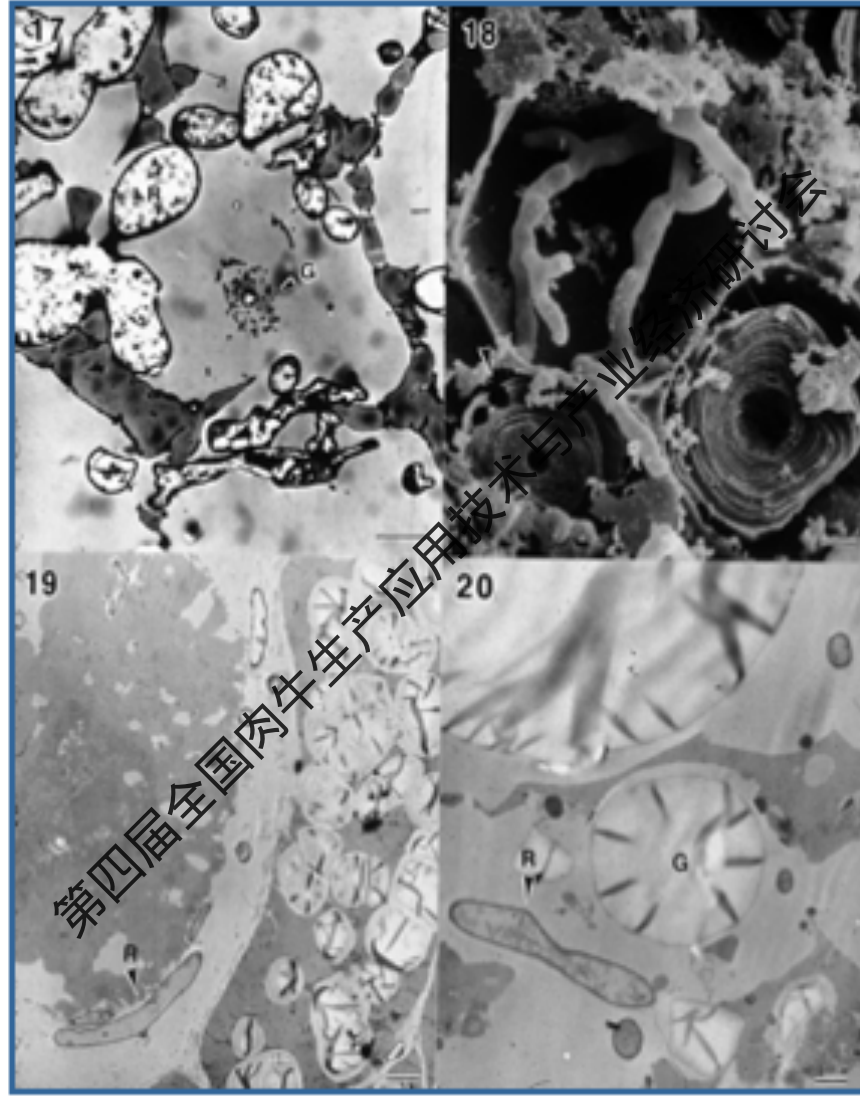


Interaction among ruminal microbes

瘤胃微生物之间的相互作用



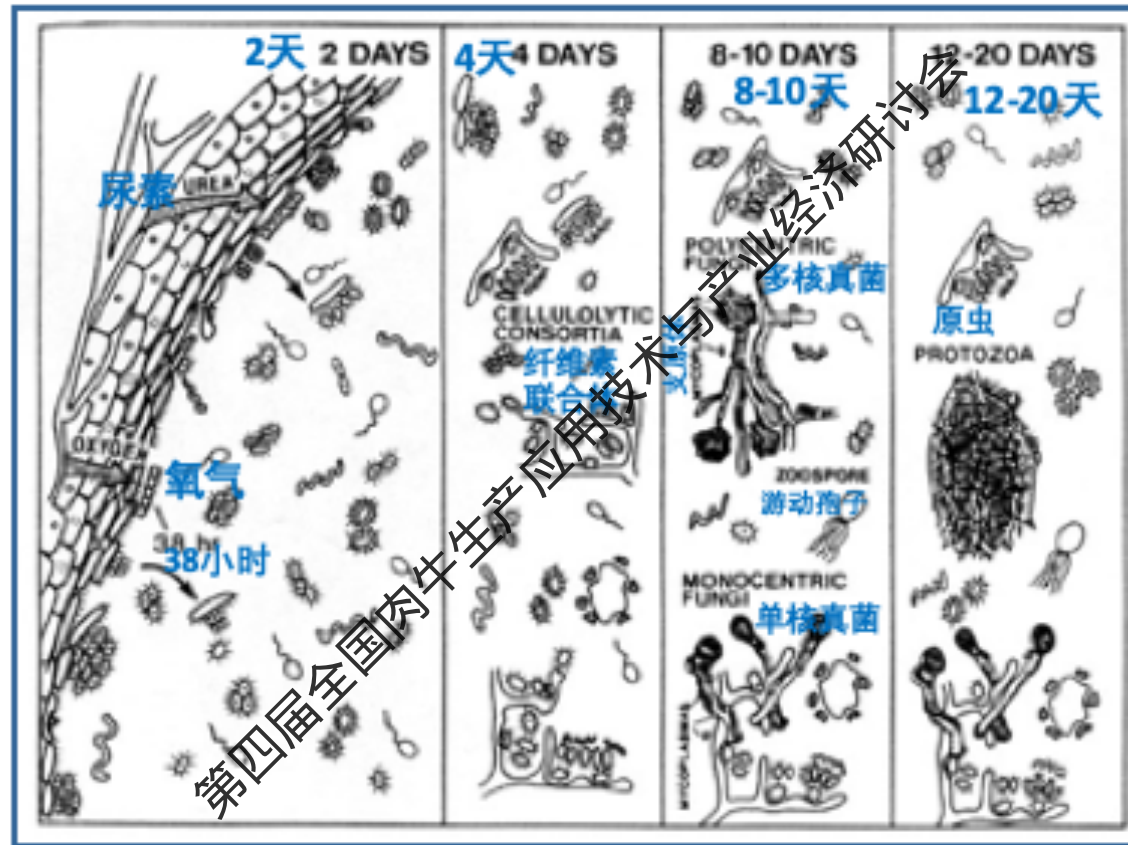
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The microbial onslaught 微生物的传播

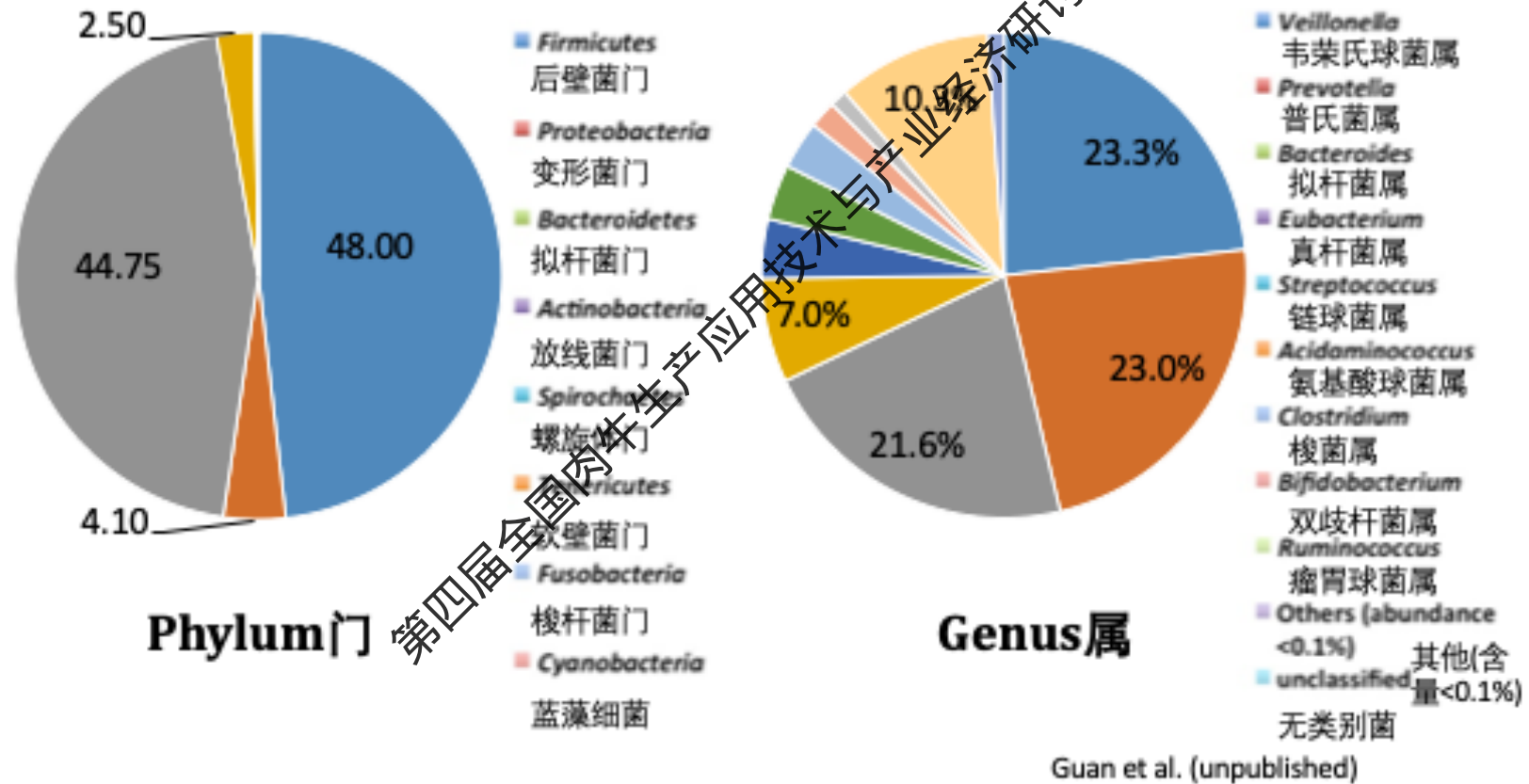


Colonization 2-20 days 定植2-20天



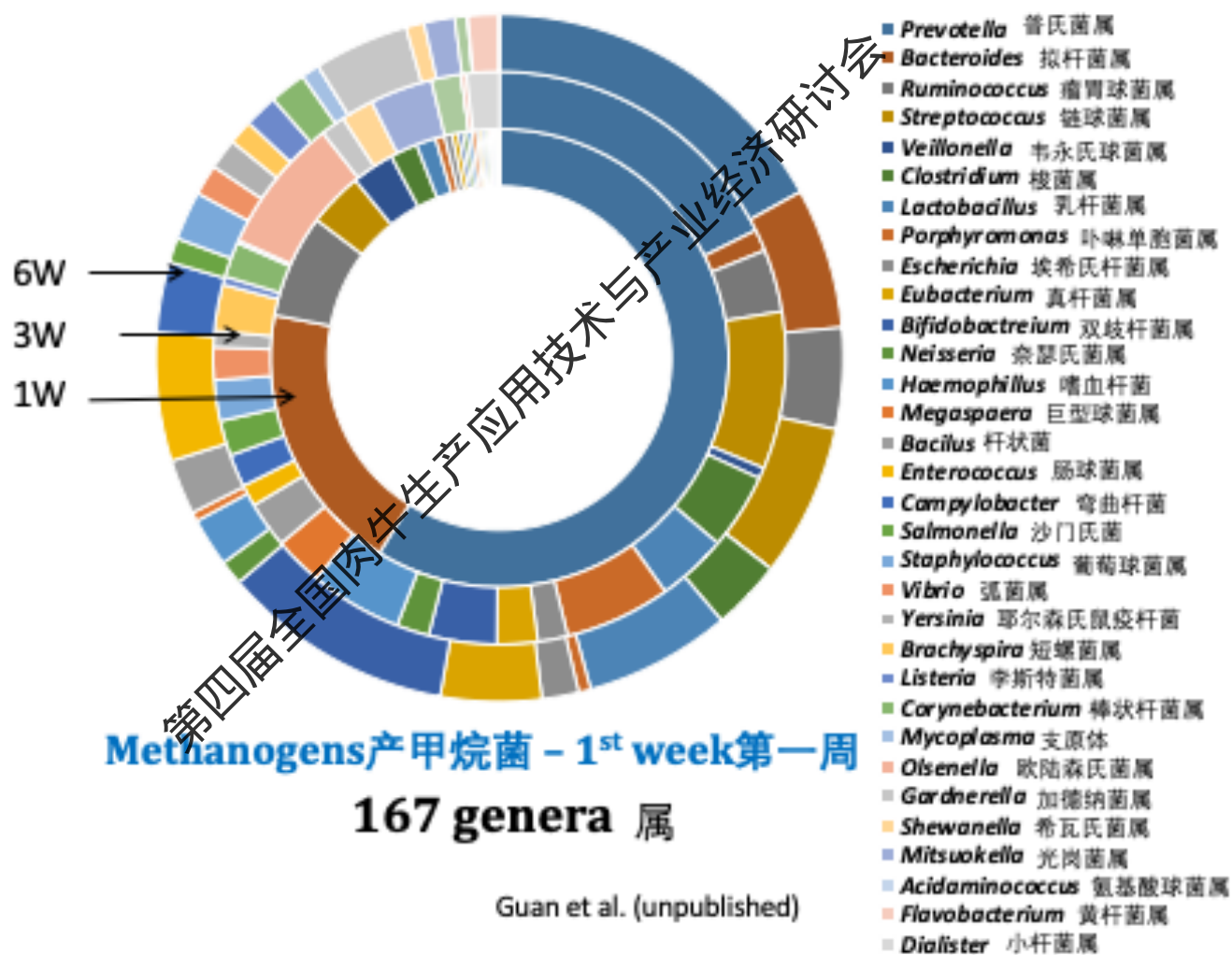
Who colonizes at birth? 出生时即定植的微生物?

83 bacterial genera, No archaea detected
83个属, 未检测到古菌



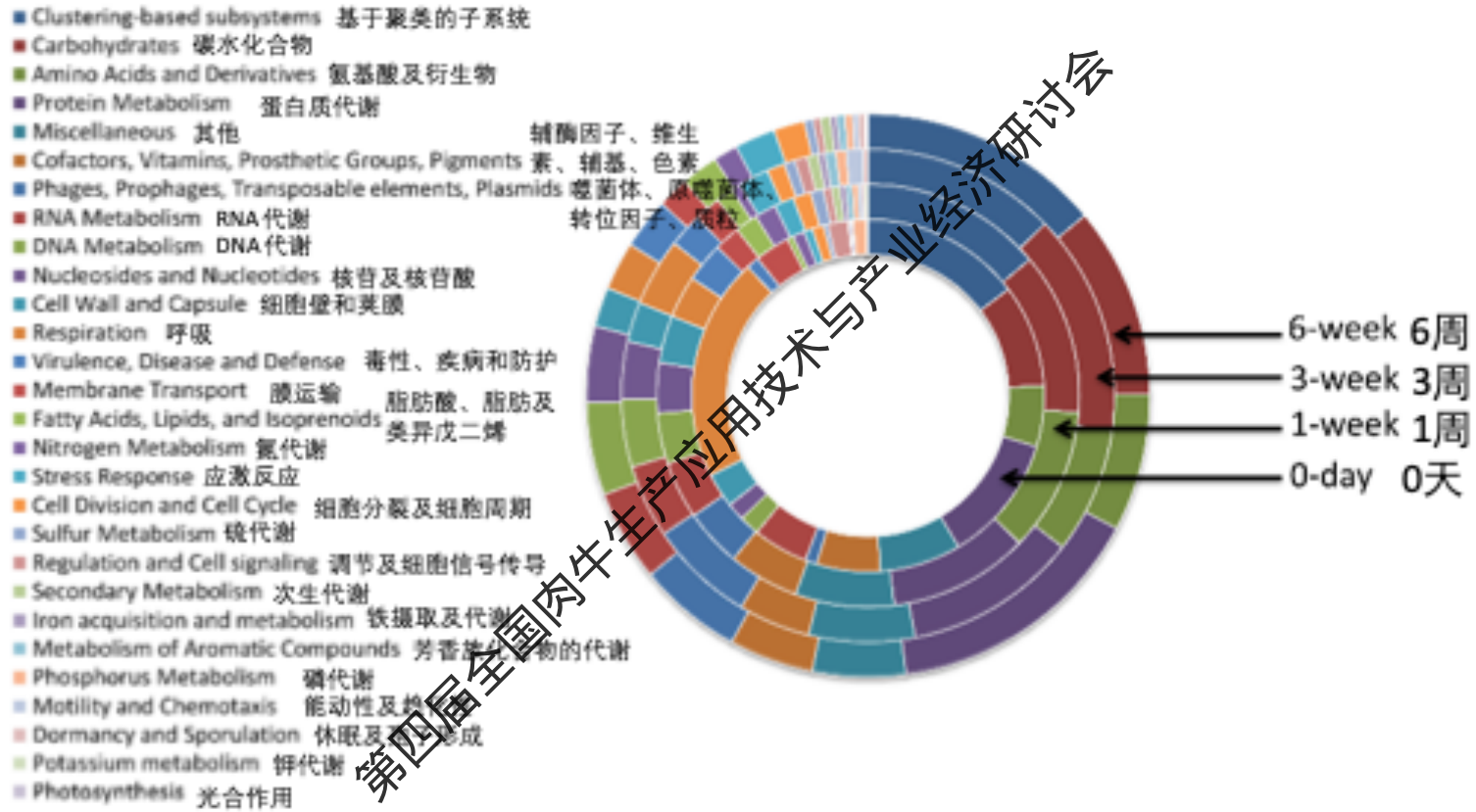
Rumen bacteria composition and diversity change through pre-weaning

断奶前瘤胃微生物组成及多样性变化



Functional changes of rumen microbiota

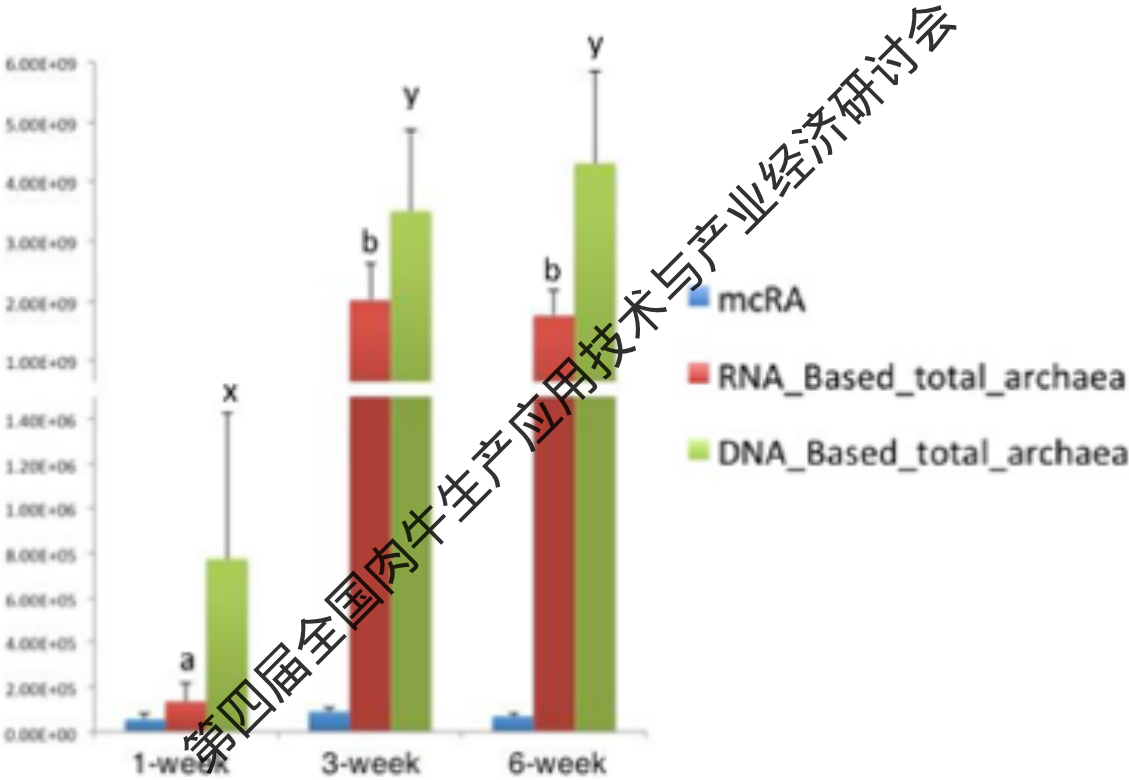
瘤胃微生物群系的功能变化



Guan et al. (unpublished)

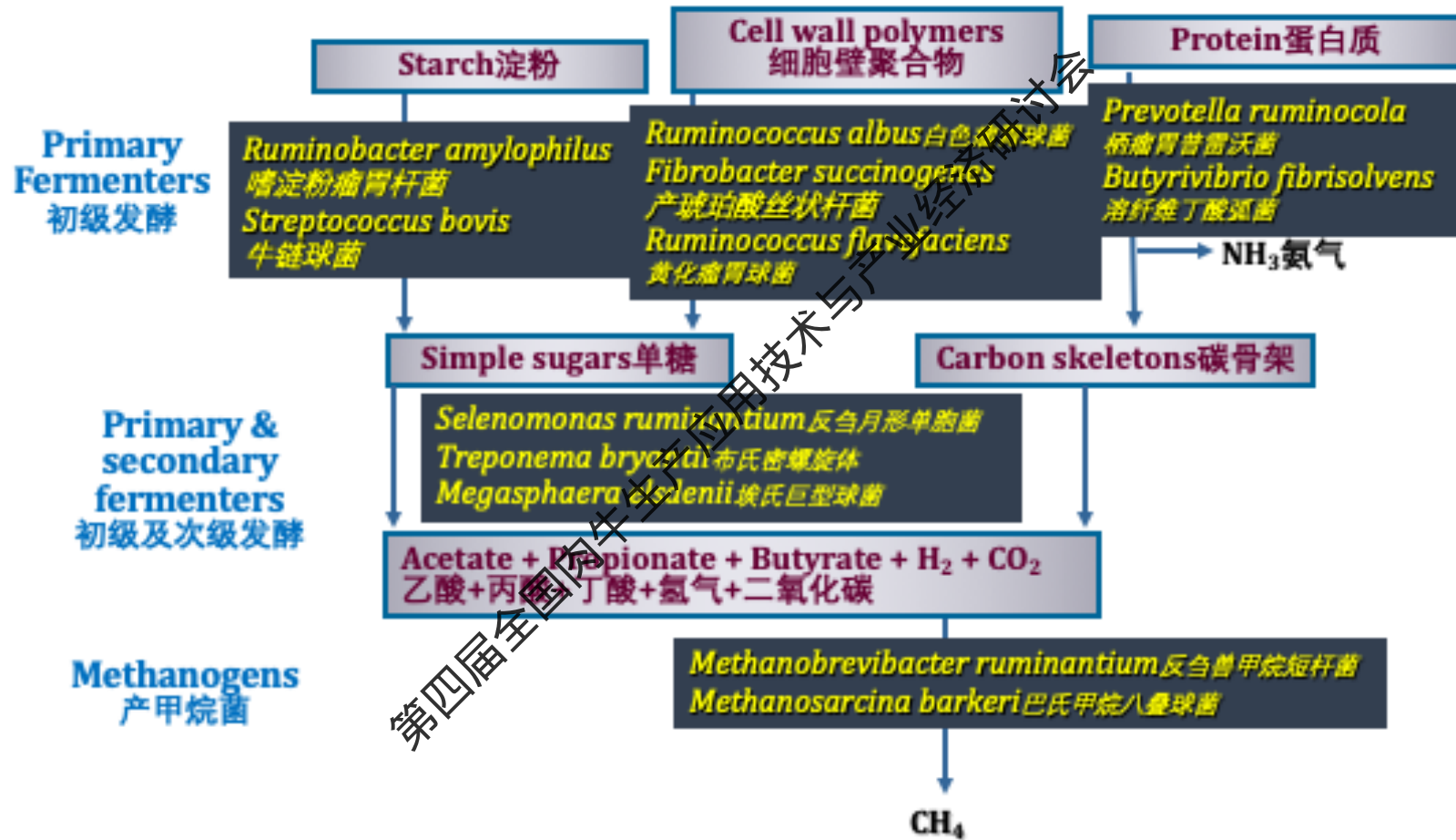
Rumen Archaea - detected from the first week

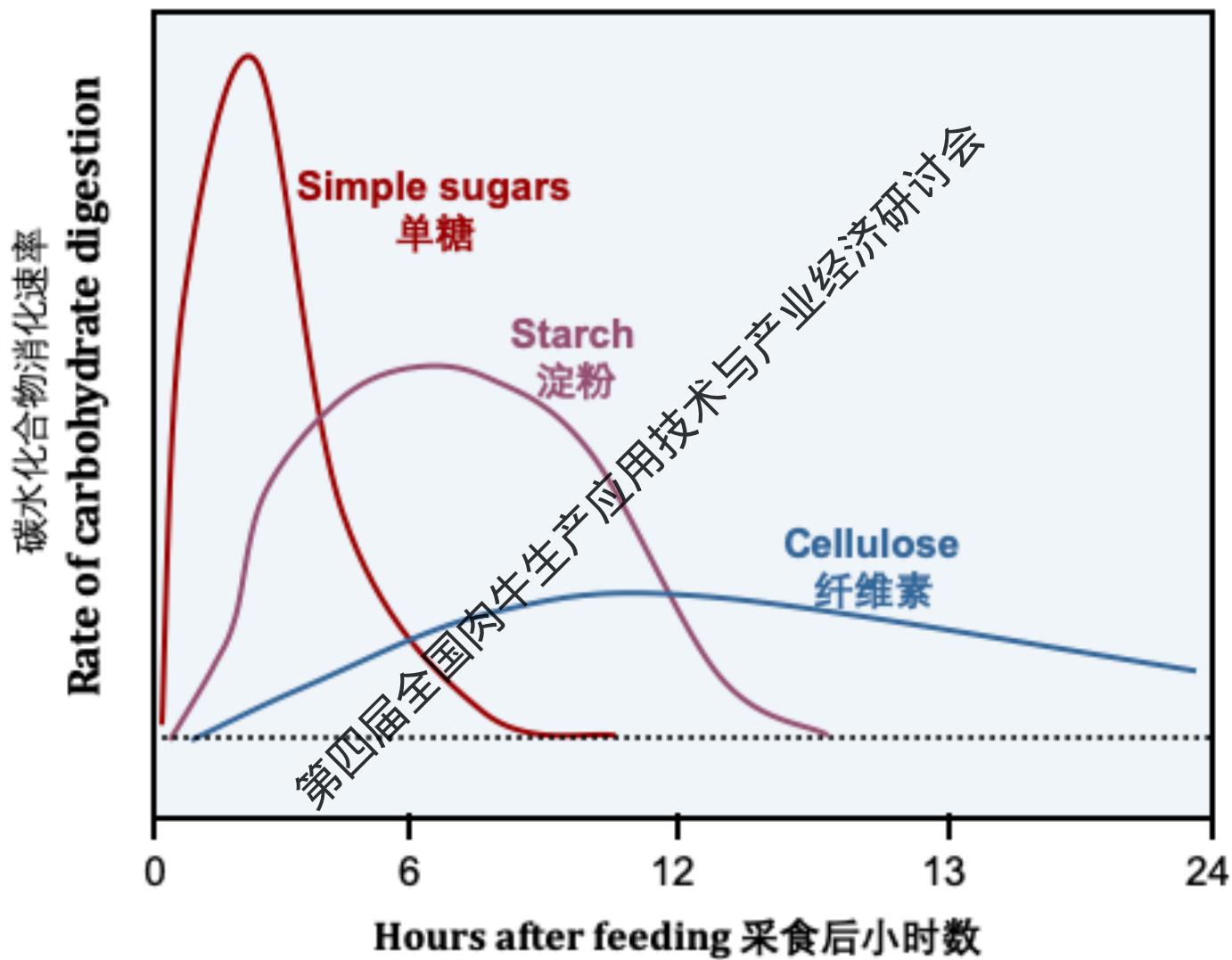
瘤胃古细菌-自第一周开始检测



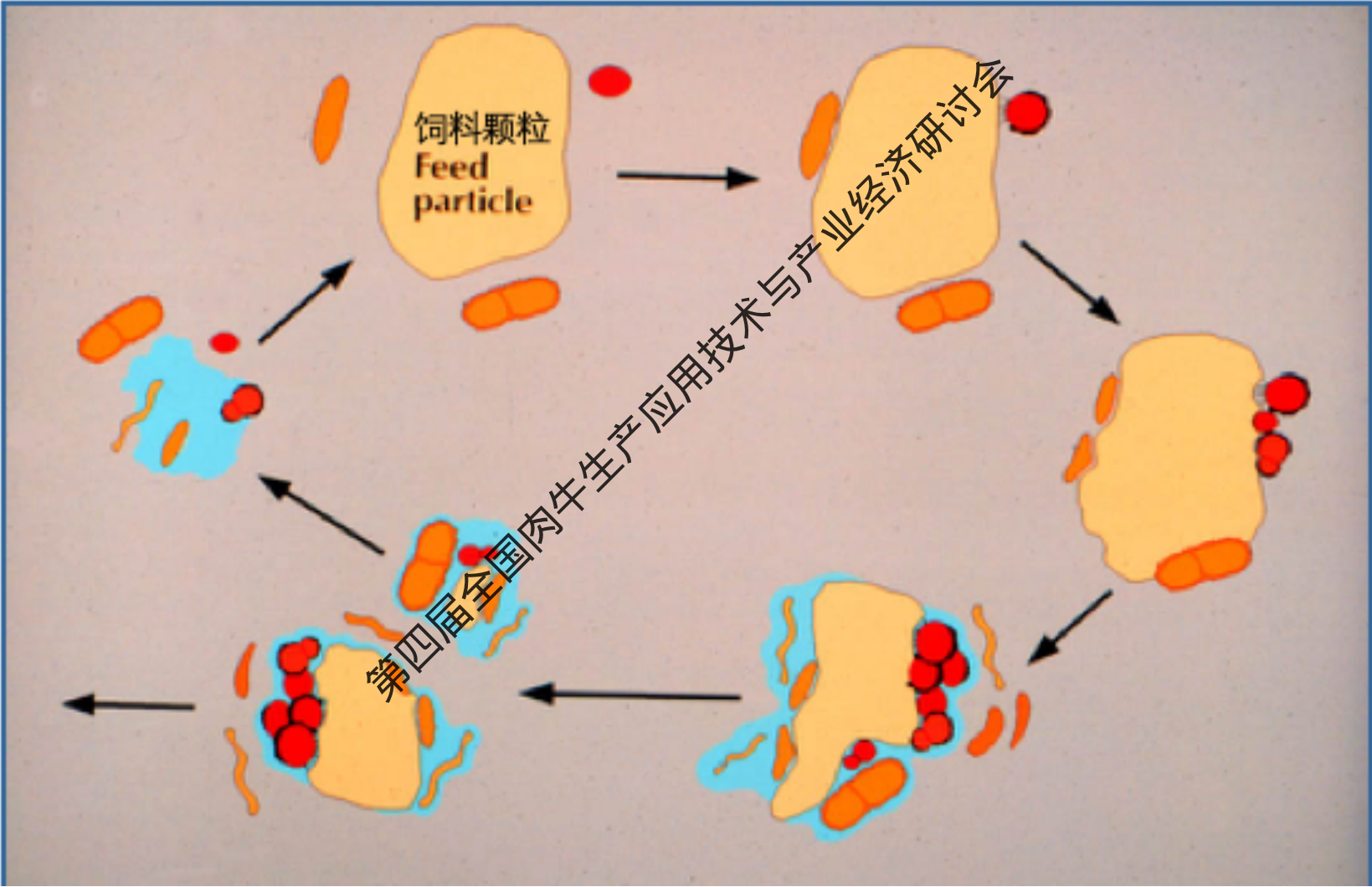
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Feed components 饲料组分

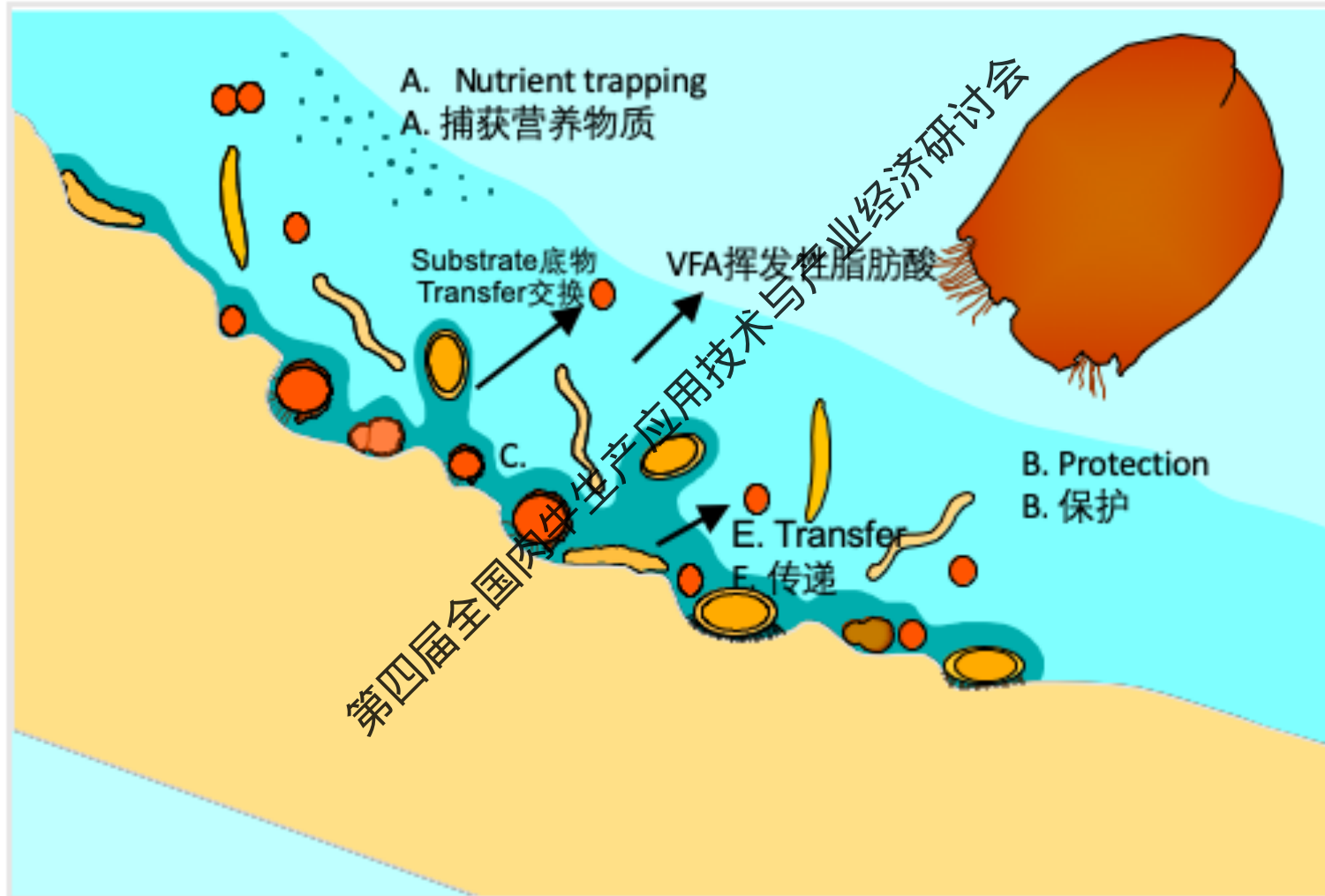




Role of the feed microbiome 饲料微生物的作用

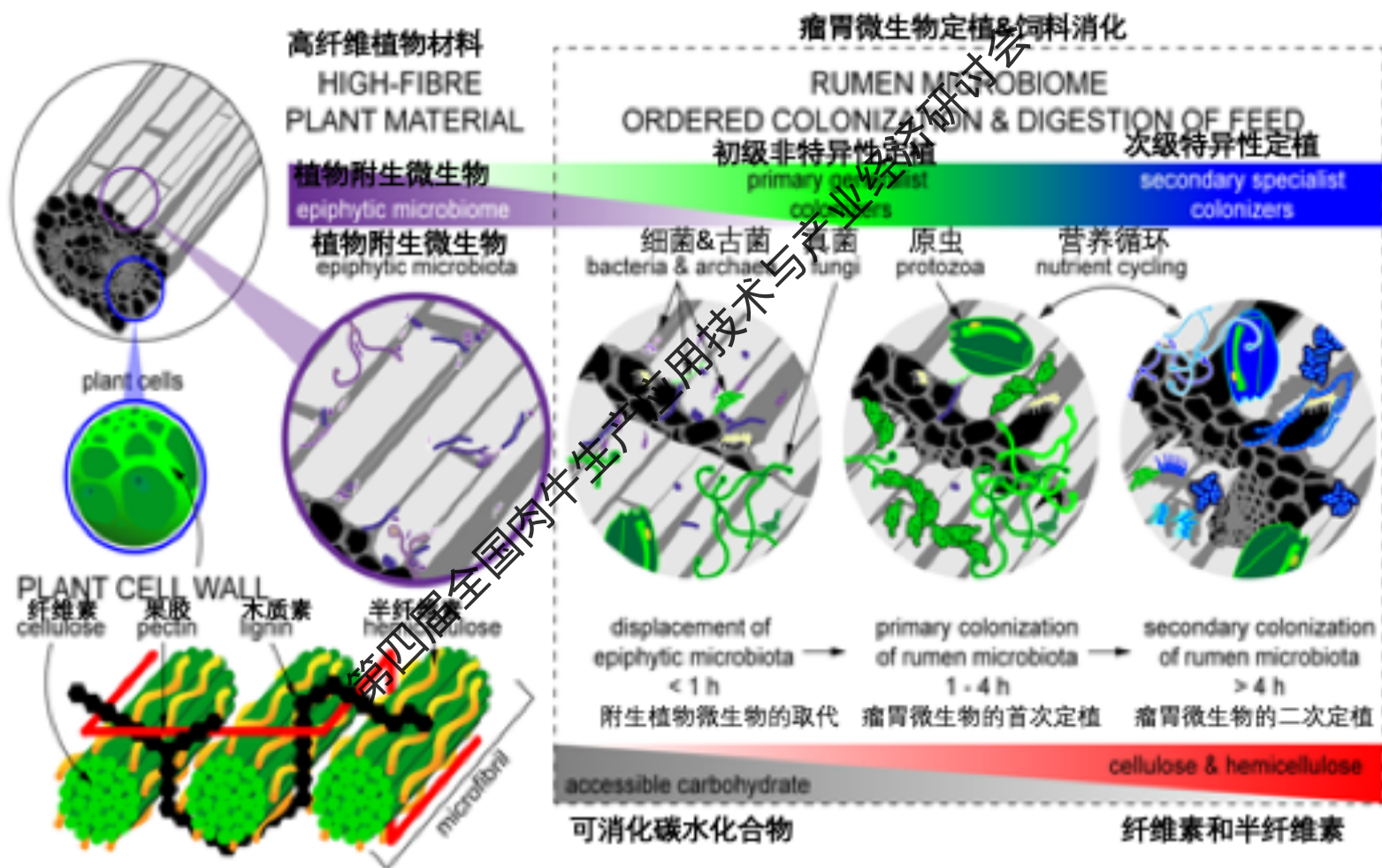


Importance of biofilms 生物膜的重要性

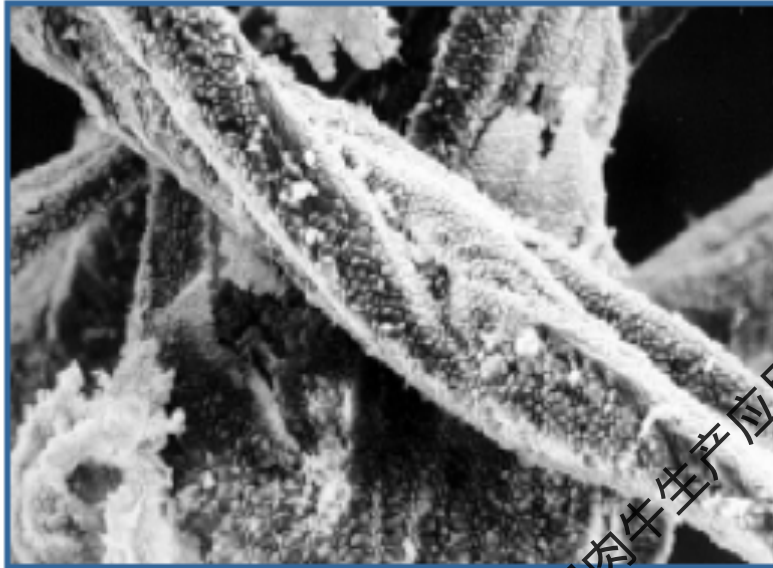


Role of rumen microbiomes in the digestion of fiber

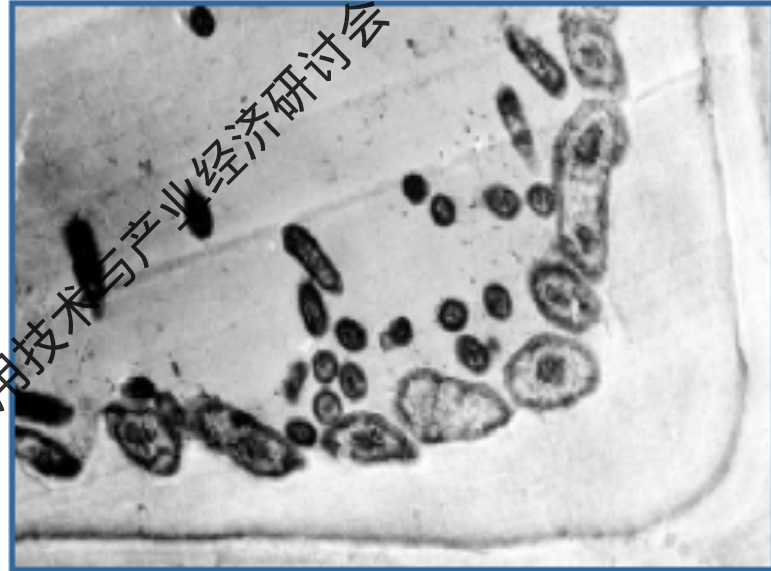
瘤胃微生物在纤维消化中的作用



***E. succinogenes* growing on cellulose & plant cell walls**
琥珀酸杆菌在纤维素及植物细胞壁上生长

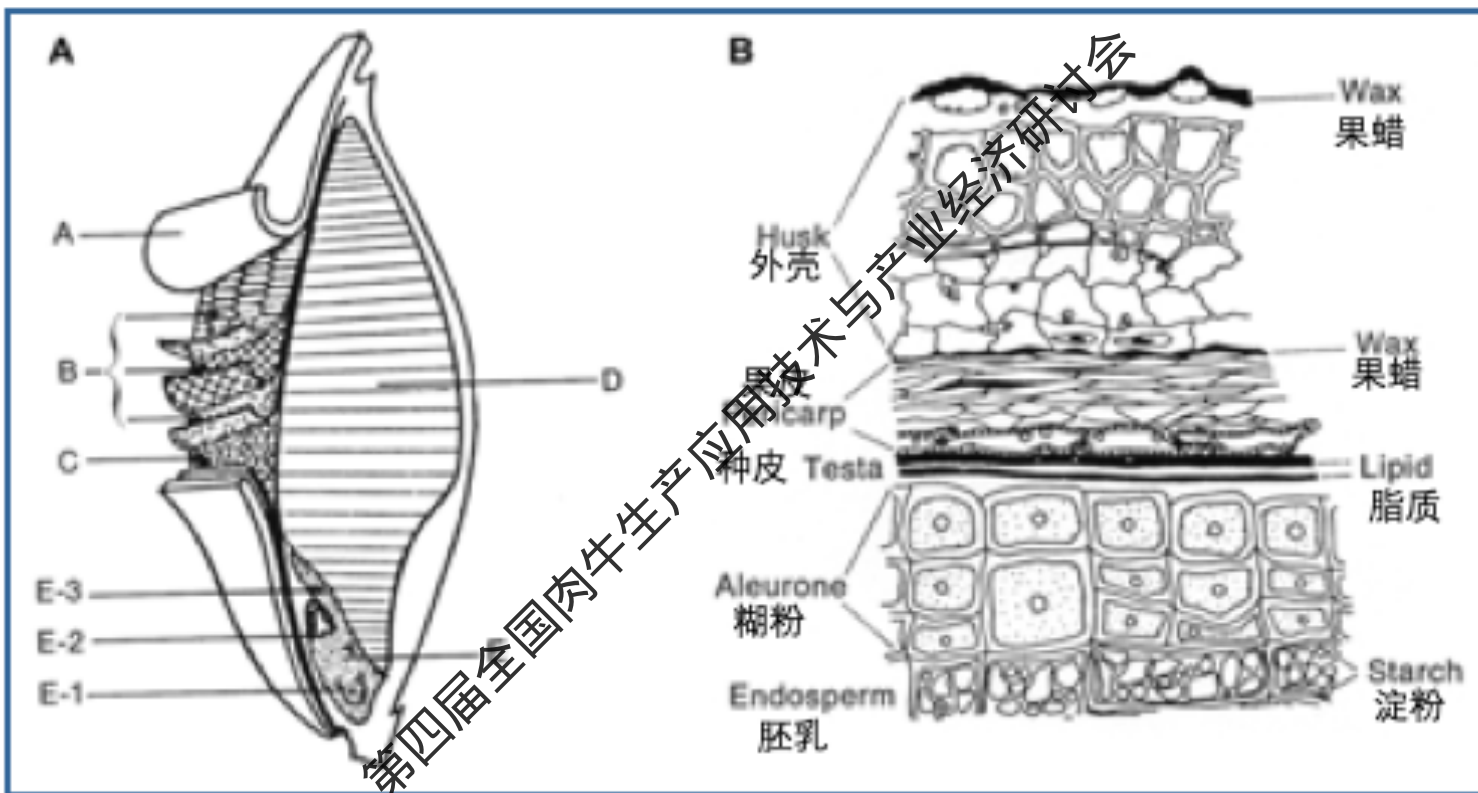


Growth on cellulose fibers
生长在纤维素纤维上

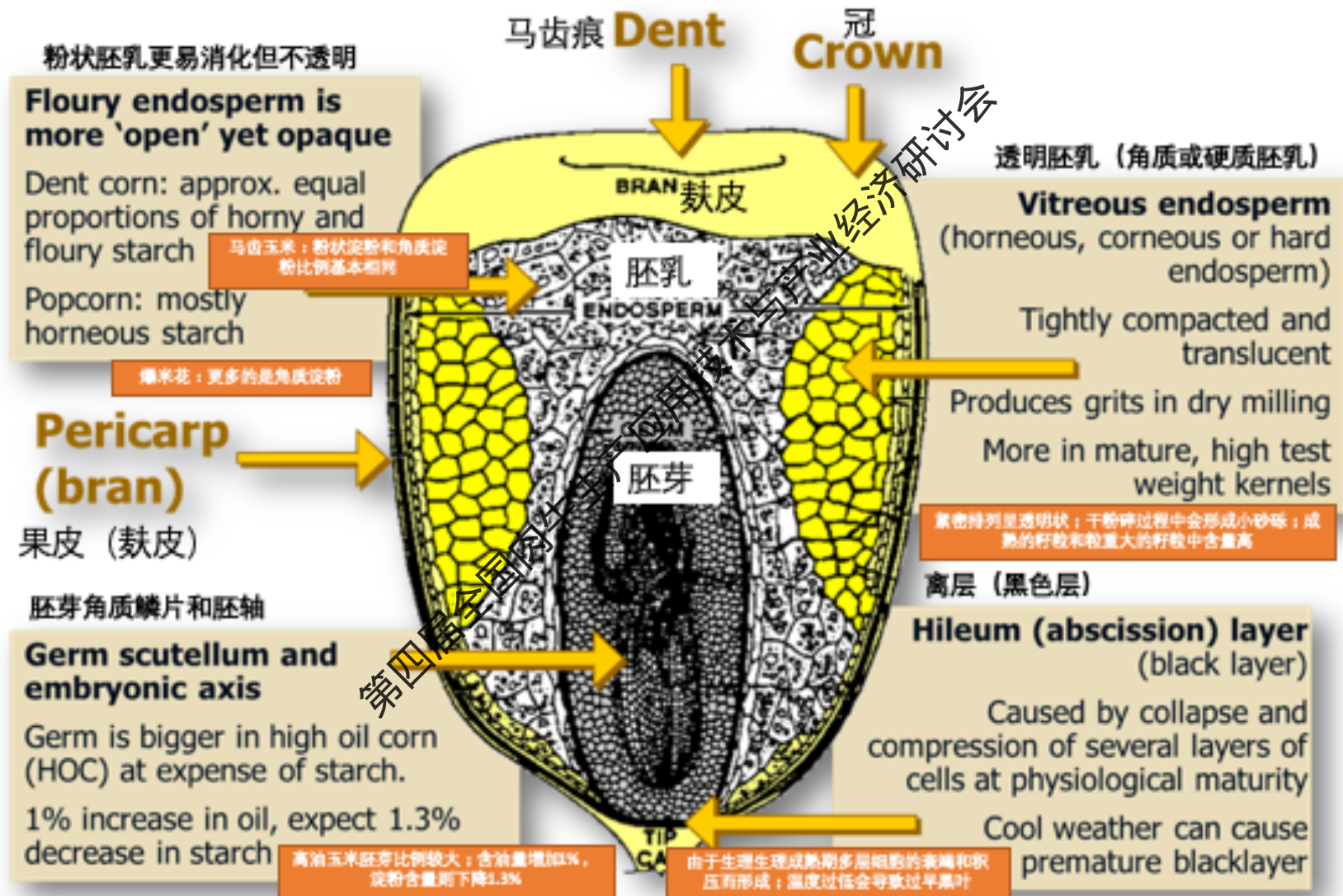


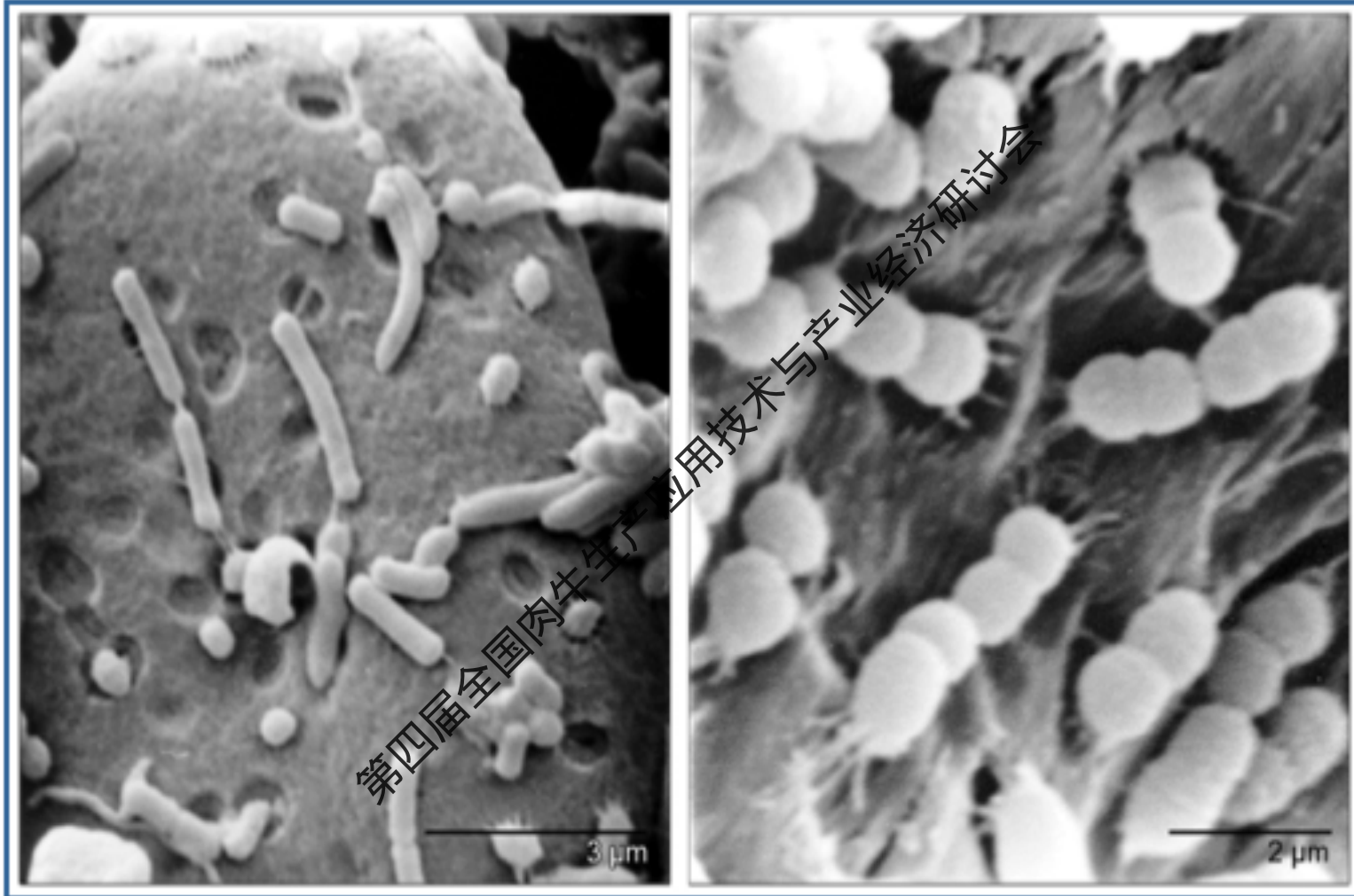
Growth on plant cell walls
生长在植物细胞壁上

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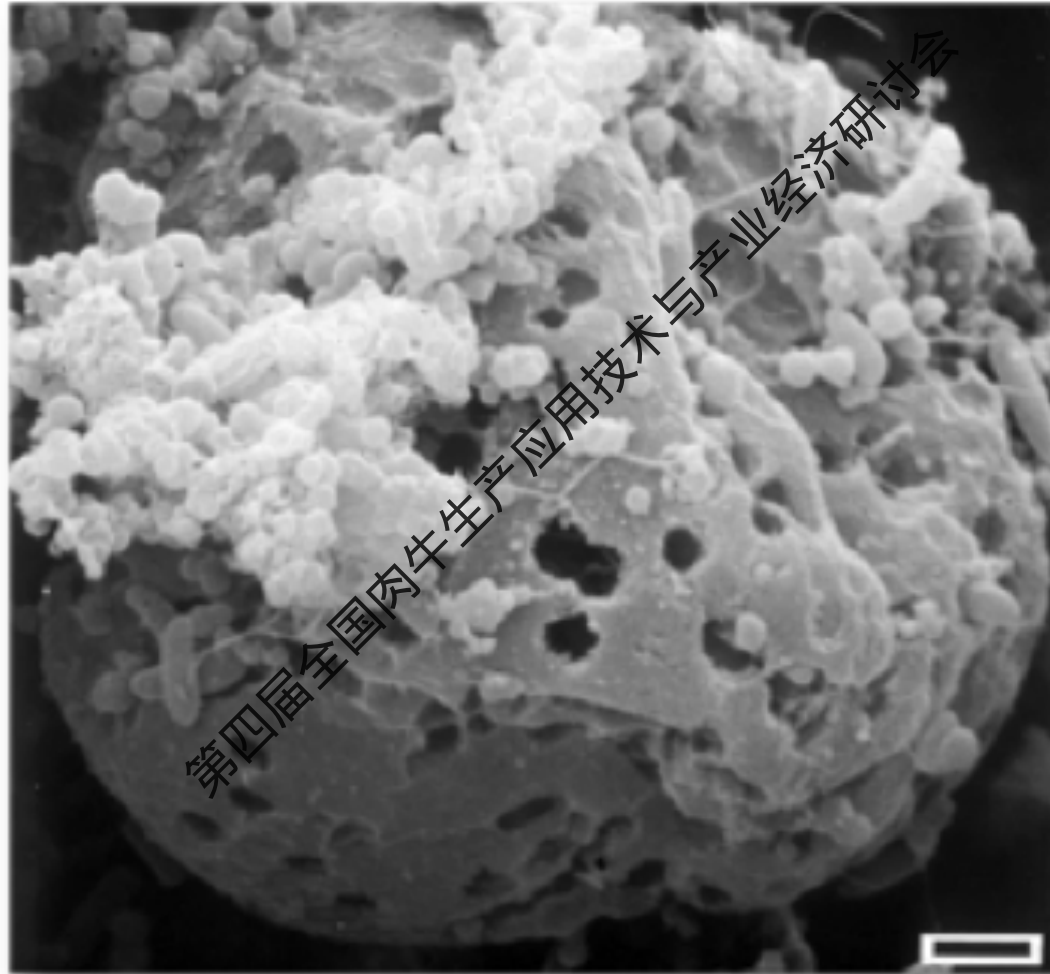


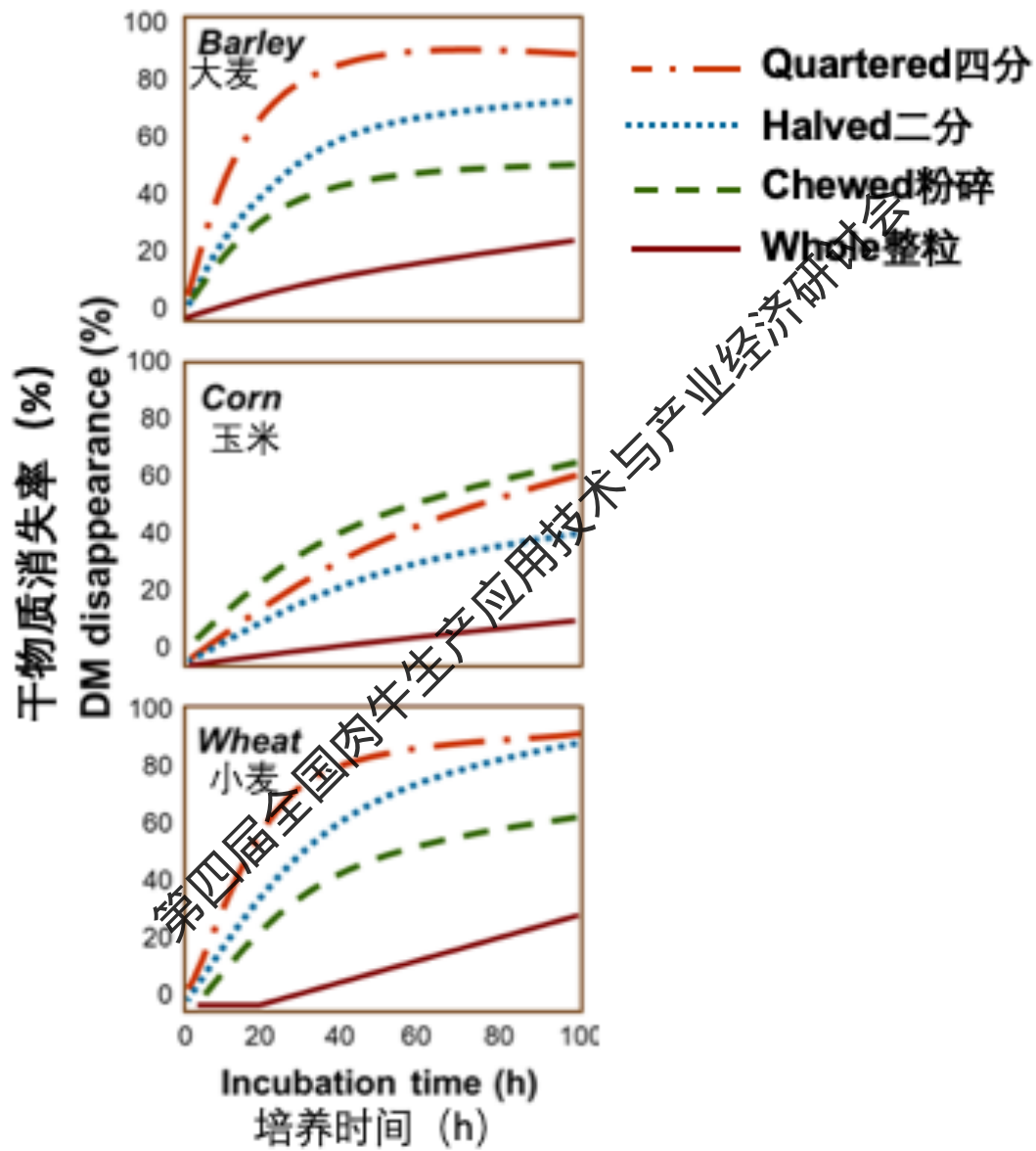
Grain Structure - Corn 谷物结构-玉米





Starch digestion in rumen 瘤胃中的淀粉消化





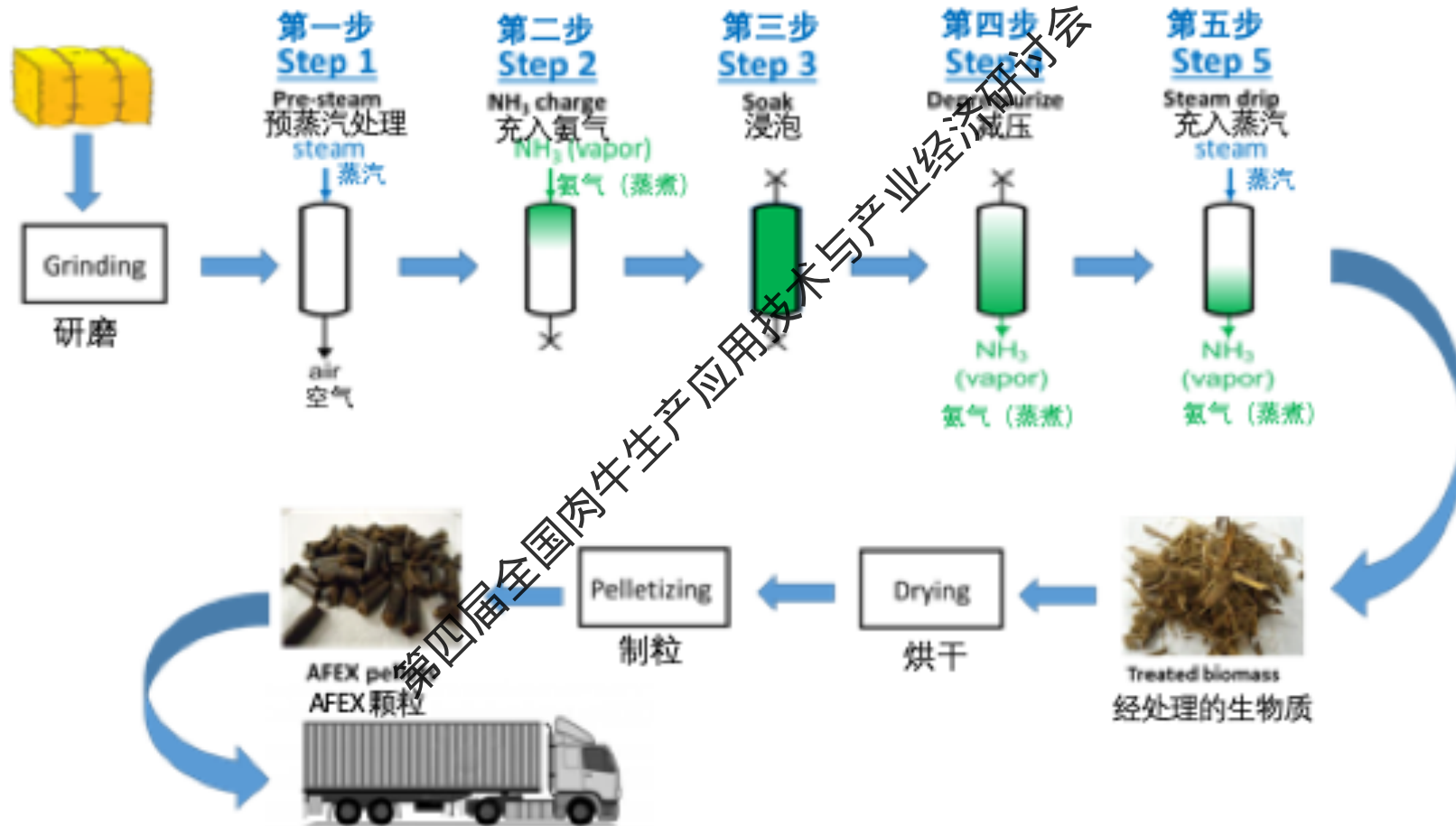


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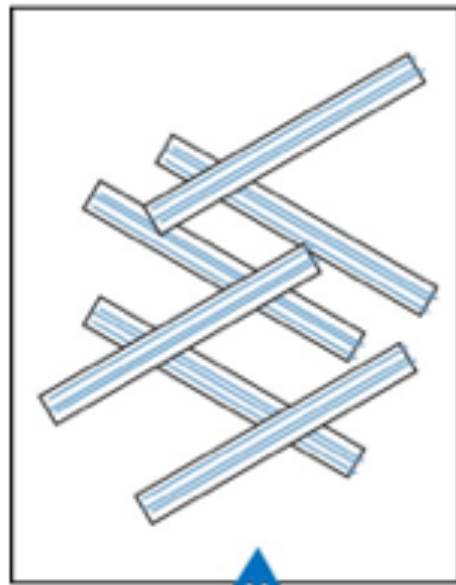


AFEX Production Process

氨化秸秆汽爆 (AFEX) 技术生产步骤



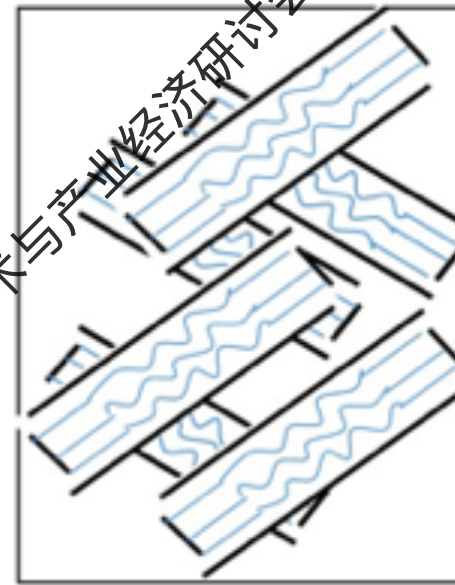
Ammonia Fiber Expansion (AFEX) 氨化秸秆汽爆 (AFEX)



Ammonia
Heat
↑ Pressure

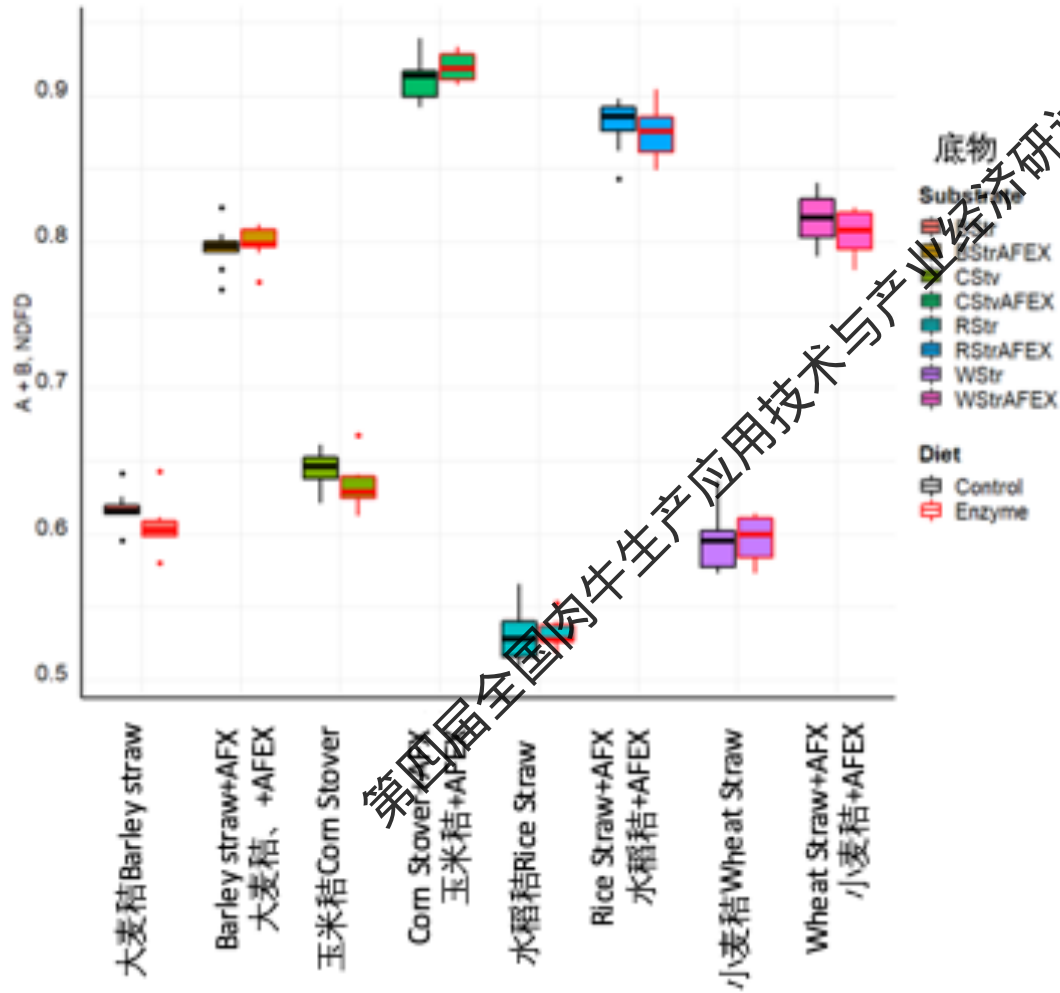
氨
加热
↑ 压力

Quick
Pressure
Release
迅速释放压力



Solubilize Lignin 木质素断裂
Disrupt Crystalline Cellulose
破坏纤维素结晶结构
Increases surface area 增加比表面积

Potentially digested fraction of NDF by crop residue with and without enzyme and with and without AFEX pretreatment
 酶和AFEX对作物秸秆中NDF潜在可消化部分的影响



Beauchemin et al. (unpublished)

Substituting AFEX wheat straw for alfalfa 氨汽爆小麦秸秆代替苜蓿

Experimental diets 试验日粮

Ingredient组分, % DM	Control 对照组	AFEX 氨膨化组
Alfalfa pellets苜蓿颗粒	50.0	20.0
AFEX straw pellets 氨汽爆秸秆颗粒	-	30.0
Barley grain 大麦粒	35.3	35.3
Corn DDGS 玉米DDGS	5.0	5.0
Canola meal 菜籽粕	5.0	5.0
Mineral/vitamin supplement 矿物质/维生素 添加剂	4.7	4.7

(Ribeiro et al. unpublished data)

Feed Digestibility 饲料消化率

Effect of AFEX wheat straw diet on total tract nutrient digestibility of lambs ($n = 8/\text{treatment}$)
氨汽爆小麦秸日粮对羊总消化道营养物质消化率的影响($n = 8/\text{处理组}$)

Item	Control 对照组	AFEX 氨膨化组	SEM	P-value
DMD 干物质消化率, %	69.5	67.8	1.93	0.20
OMD 有机物消化率, % of DM	71.9	69.5	1.87	0.09
CPD 粗蛋白消化率, % of DM	74.1	69.6	1.16	< 0.001
NDFD NDF 消化率, % of DM	43.9	50.0	3.84	0.05
ADFD ADF 消化率, % of DM	44.1	50.3	3.72	0.03

(Ribeiro et al. unpublished data)

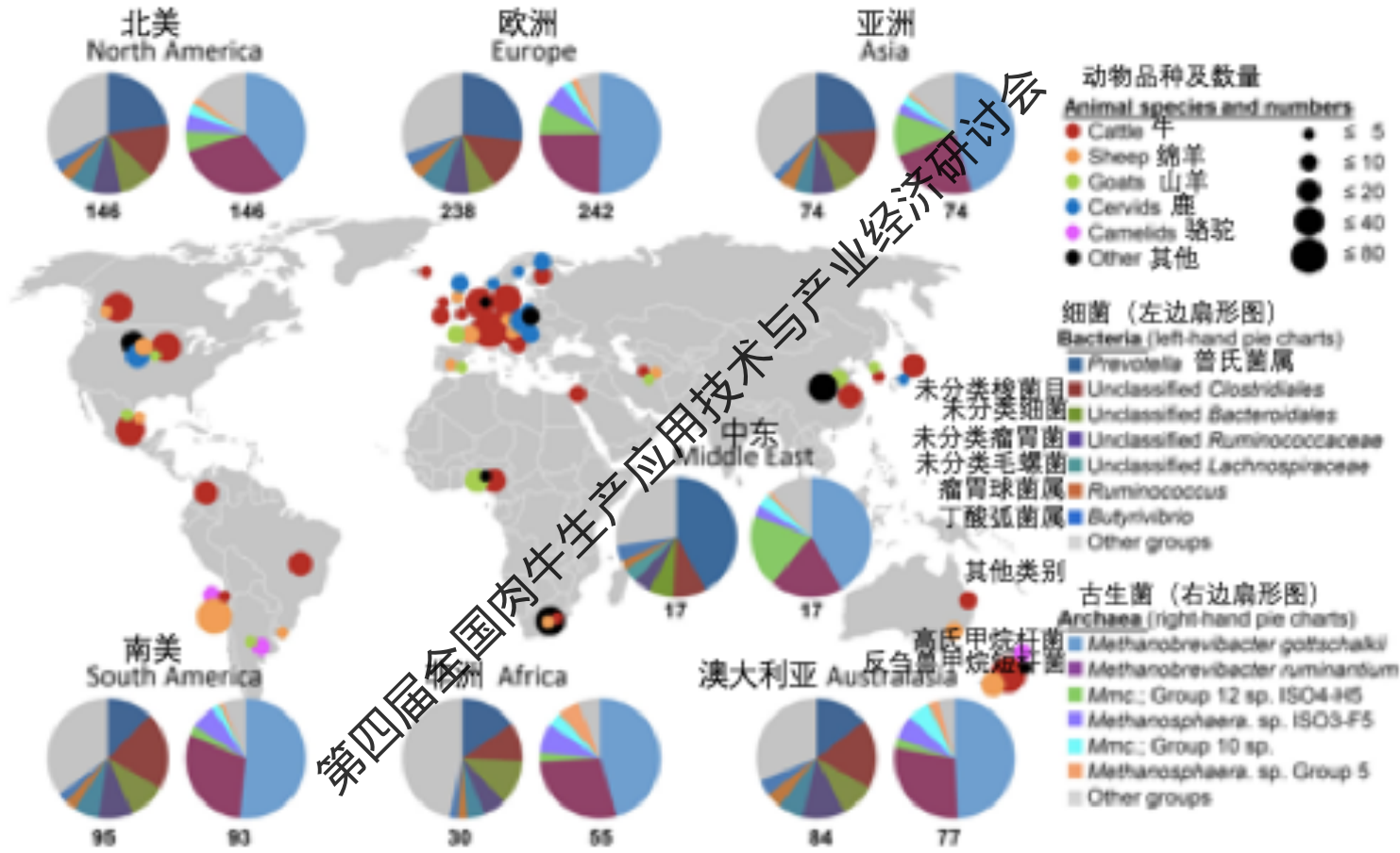
Lamb Growth Performance 羊生产性能

Effect of AFEX wheat straw diet on intake, production performance, and carcass characteristics of finishing lambs ($n = 30/\text{treatment}$)
氨膨化小麦秸对肥育羊采食量、生产性能和屠宰性能的影响($n = 30/\text{处理组}$)

Item	Control对照组	AFEX氨膨化组	SEM	P-value
DMI 干物质采食量, kg/d	1.50	1.61	0.088	< 0.01
ADG 日增重, g/d	298	305	51.1	0.51
G:F 增重 : 采食量	0.199	0.188	0.0223	0.04
DOF 饲喂天数, d	97	91	-	0.04
HCW 热胴体重, kg	23.5	23.8	2.28	0.66
Dressing percentage 屠宰率	45.7	46.0	0.57	0.58

(Ribeiro et al. unpublished data)

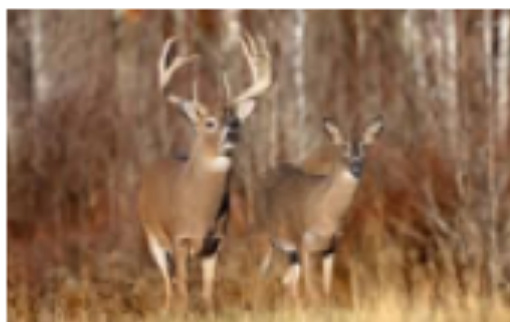
Factors: Animal species 因素：动物种类



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Elk 麋鹿



White tail deer 白尾鹿



Moose 驼鹿



Bison 北美野牛



Musk Oxen 麝香牛



Mule deer 北美黑尾鹿



Beaver 海狸

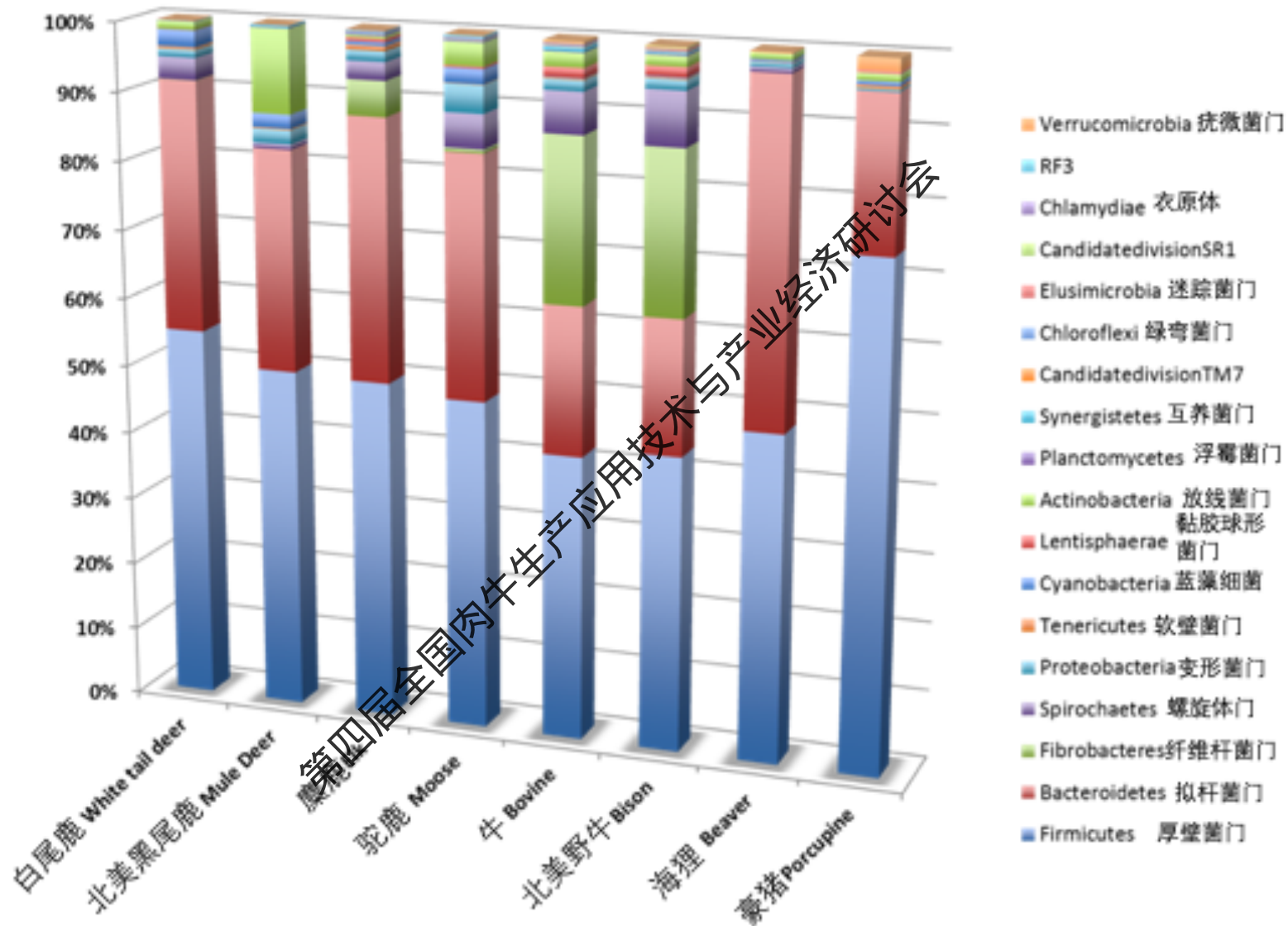


Porcupine 豪猪



Cattle 牛

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Bacterial diversity at phylum level 门级细菌多样性

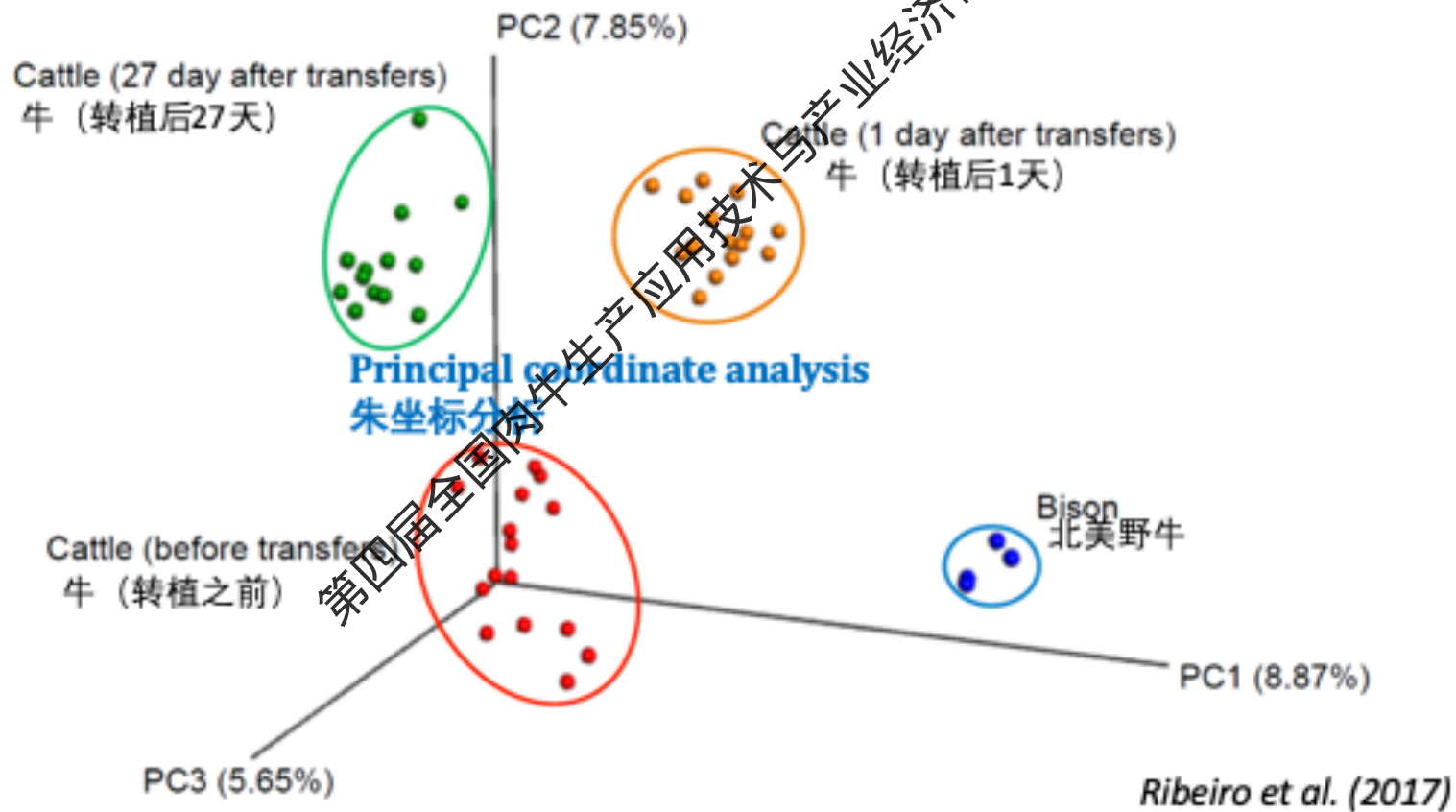
Gruninger and McAllister



Ribeiro et al. (2017)

Principal coordinate analysis (PCoA) of ruminal bacterial OTUs

瘤胃微生物OTUs的主坐标分析



Protozoa population 原虫数量

	Transfers 转植		SEM	Time	P-value	
	Before	After			Transfer	Time × Transfer
Total Protozoa 总原虫数, ×10⁴						
Before feeding 饲喂前	7.5	10.0	0.55	0.02	<0.01	0.67
6 h after feeding 饲喂6h后	6.4	8.5				
Entodinium 内毛虫属, %¹						
Before feeding 饲喂前	73.1	57.2	2.77	0.35	<0.01	0.23
6 h after feeding 饲喂6h后	67.8	57.9				
Ostracodinium 硬甲双毛属, %¹						
Before feeding 饲喂前	7.2	21.2	1.88	0.35	<0.01	0.41
6 h after feeding 饲喂6h后	7.0	18.2				

Ribeiro et al. (2017)

Animal variation 动物变化

After transfer 转植后

Animal	Period	NDFD
9	1	61.1
11	1	57.4
7	1	57.1
12	1	55.0
15	1	54.7
17	1	54.0
1	1	53.6
10	1	52.6
8	1	51.7
6	1	51.0
18	1	50.4
19	1	48.9
2	1	45.9
21	1	45.0
14	1	45.0
4	1	42.2
Mean	SD	
51.8	4.9	

Before transfer 转植前

Animal	Period	NDFD
11	2	56.0
17	2	55.1
10	2	54.5
15	2	53.4
19	2	52.6
7	2	52.5
2	2	51.9
4	2	51.7
18	2	51.3
8	2	51.1
21	2	50.6
9	2	49.6
14	2	48.9
12	2	46.5
1	2	45.0
6	2	43.9
Mean	SD	
50.9	3.3	

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Cow-calf
育犊母牛

犊牛春天出生，然后随母牛一同在草场放牧

Calf born in spring and left to pasture with mother

Cows rebred in summer

母牛夏季重新配种

犊牛7个月左右断奶

Calf weaned at ~7 months

- ① **Calf-fed:** Weaned calf (450-600 lbs) moved directly to finishing feedlot
犊牛饲喂：断奶犊牛（450-600磅）直接转移到肥育场
- ② **Backgrounder:** Weaned calf backgrounded in feedlot
育前牛：断奶犊牛在肥育场中粗饲
- ③ **Yearling fed:** Weaned calf backgrounded in pasture
周岁牛：断奶犊牛分别在肥育场和草场中进行粗饲



育前牛 Backgrounding

体重在450-600磅左右，犊牛被卖掉在肥育场或草场上粗饲，饲喂粗饲料基础日粮

At 450-600 lbs, calf sold to backgrounding operation in pasture or in feedlot on forage-based diet



肥育牛 Finishing

Calf fed on forage and grain. Average time spent in feedlot: 9 months ①, 5 months ②, or 3 months ③

Calf fed to slaughter weight of 1,350-1,400 lbs
体重达到1350-1400磅后屠宰

犊牛饲喂粗饲料和谷物。在肥育场的平均时间为：① 9个月；② 5个月；③ 3个月。

犊牛肥育场粗饲至13月龄，然后在牧场粗饲至17月龄

② backgrounded in feedlot ~7-13 months, on pasture ~13-17 months

犊牛7~13月龄在肥育场中粗饲，饲喂草或高比例粗料。

Calf backgrounded in feedlot from ~7-13 months. Fed on grass and/or higher forage

Calf moved to finishing feedlot

犊牛转移去肥育场

犊牛转移去肥育场

Calf moved to finishing feedlot



耕地 Cropland

Croplands provide forage, silage and grain
耕地供应饲草、青贮和谷物

Relative taxa abundance of forage, mixed forage, and high grain dietary rumen microbiomes

饲喂粗饲料、混合粗饲料和高精饲时瘤胃微生物群的相对分类群丰度

分类级 Taxa Level	分类 Classification	Dietary Treatment 日粮处理 (% abundance 丰度)		
		Forage 粗饲料	Mixed Forage 混合粗饲料	High Grain 高精料
Phyla 门	Bacteroidetes 拟杆菌门	25.7	26.2	40.3
Class 纲	Bacteroidia 拟杆菌纲	24.2	24.9	37.7
Order 目	Bacteroidales 拟杆菌目	24.1	24.9	37.7
Family 科	S24-7	3.8	2.2	
Genus 属	RC9	3.3	2.7	
Family 科	Prevotellaceae 普雷沃氏菌科	12.0	16.3	32.7
Genus 属	Prevotella 普氏菌属	8.9	12.8	31.6
Family 科	Rikenellaceae 理研菌科	3.7	3.0	
Phyla 门	Firmicutes 厚壁菌门	55.2	55.8	37.0
Class 纲	Clostridia 梭菌属	53.3	53.9	34.9
Order 目	Clostridiales 梭菌目	53.1	53.4	34.5
Family 科	Lachnospiraceae 毛螺菌科	32.1	22.7	16.9
Family 科	Clostridiaceae 梭菌科	0.9	1.2	
Phyla 门	Proteobacteria 变形菌门	4.7	8.9	17.9

Petri et al. (2013; PLoS ONE 8(12): e83424.)

Dietary strategies to reduce methane emissions

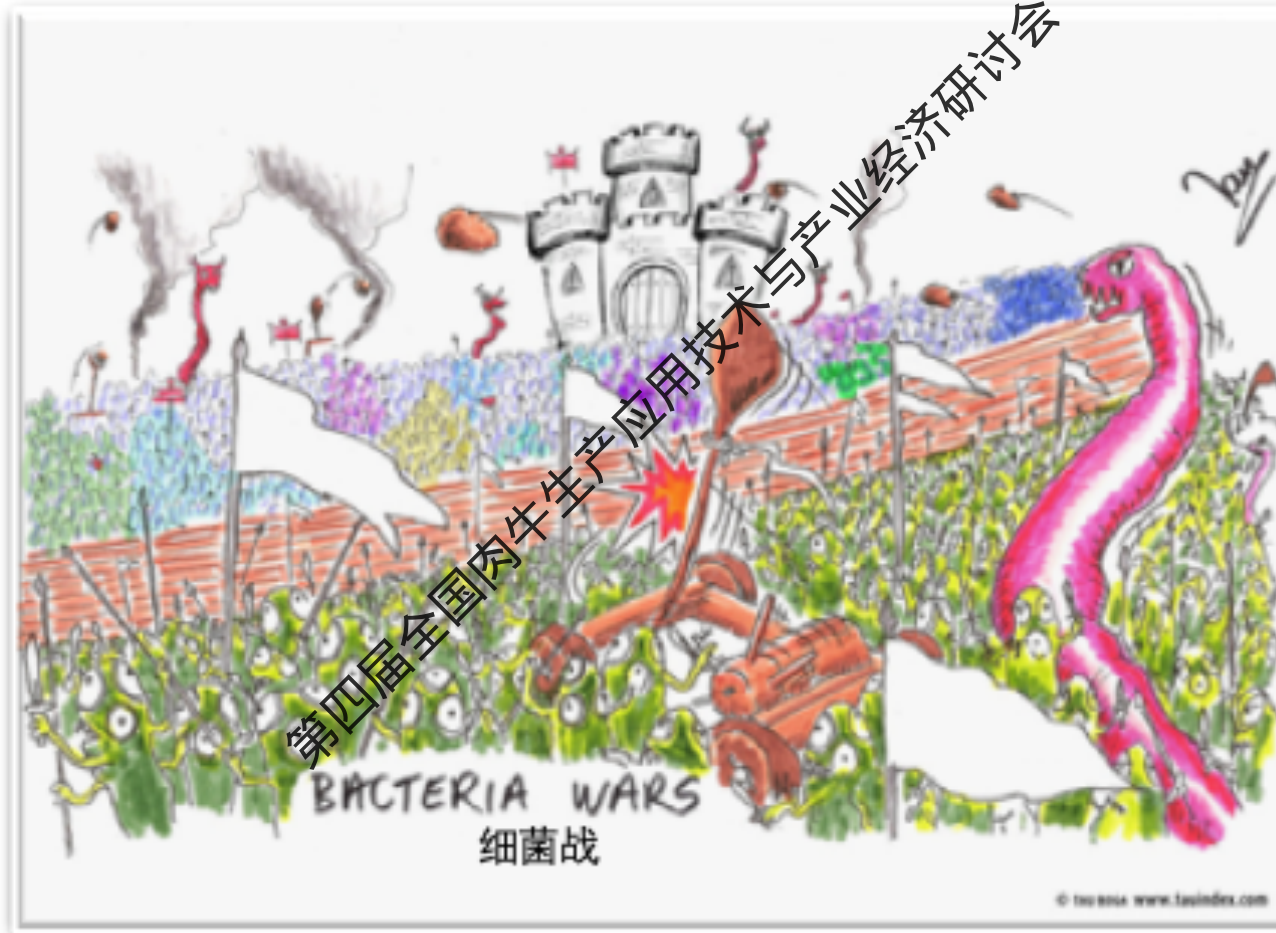
营养调控进行甲烷减排

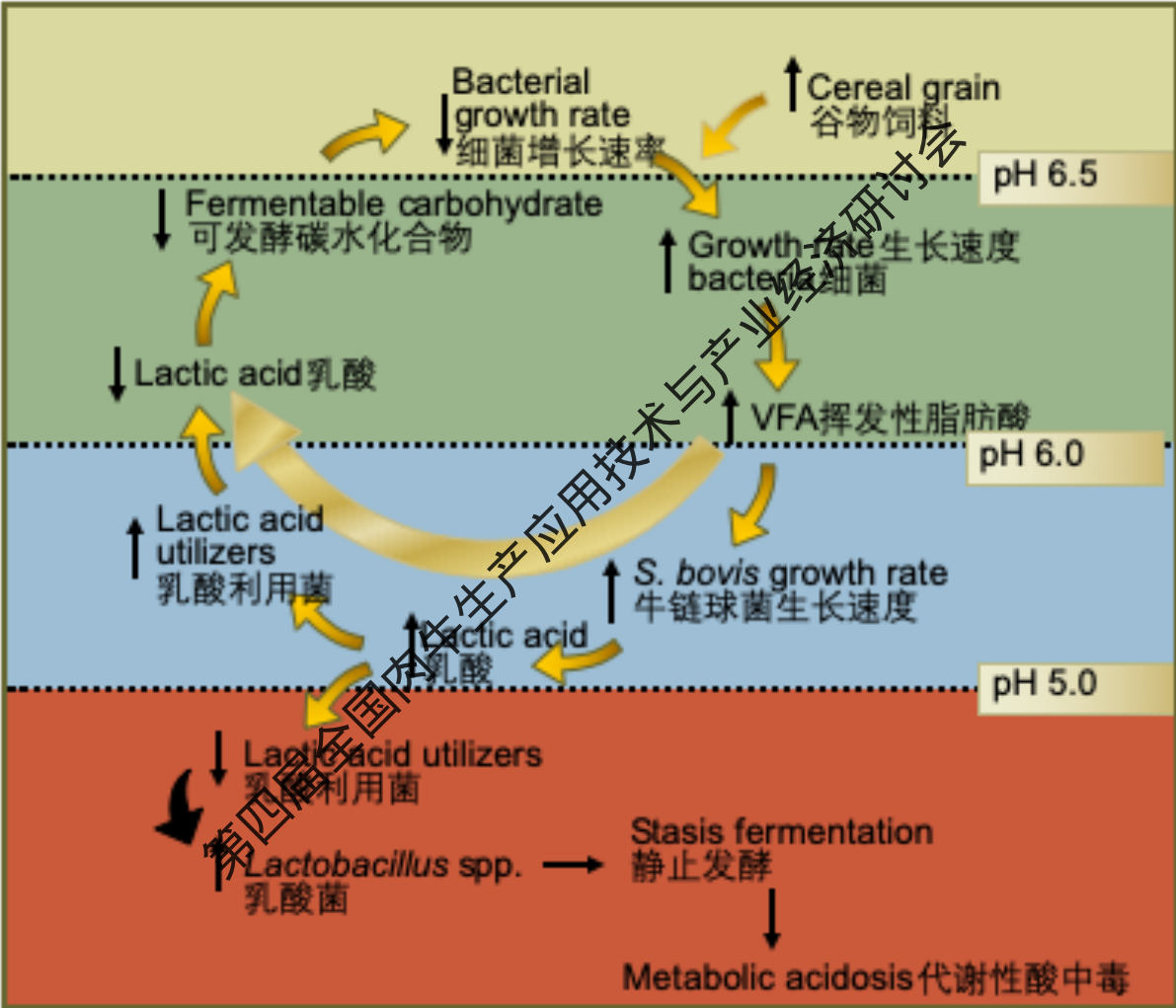
	Methane mitigation effect 甲烷减排效应	Long-term mitigation effect 长效作用	Safety 安全性
Inhibitors 抑制剂			
3-nitrooxypropanol 3-硝基酯-1-丙醇	Medium 中	?	?
Electron receptors 电子受体			
Nitroethane 硝基乙烷	Low 低	No 否	No 否
Nitrate 硝酸盐	High 高	No? 否?	Yes? 是?
Ionophores 离子载体	Low 低	No? 否?	Yes? 是?
Plant bioactive compounds 植物源生物活性化合物			
Tannins (condensed) 单宁 (浓缩)	Low 低	No? 否?	Yes? 是?
Saponins 皂苷	Low? 低?	No 否	No? 否?
Essential oils 精油	Low? 低?	No 否	No 否
Bacterial direct fed microbials 直接饲喂微生物	Low? 低?	No 否	Yes 是
Defaunation 驱除原虫	Low 低	No 否	No 否
Dietary lipids 食用油脂	Medium 中	No? 否?	Yes? 是?
Inclusion of concentrate 提高精饲料饲喂量	Low to medium 中低等	Yes 是	Yes? 是?
Improving forage quality 提高粗饲料品质	Low to medium 中低等	Yes 是	Yes 是
Grazing management 放牧管理	Low 低	Yes 是	Yes 是
Feed processing 饲料加工	Low 低	Yes 是	Yes 是
Mixed rations and feeding frequency 混合比例和饲喂频率	?	?	?
Precision (balanced) feeding and feed analysis 精准 (平衡) 饲养和饲料分析	Low to medium 中低等	Yes 是	Yes 是

(Hristov et al., 2013)

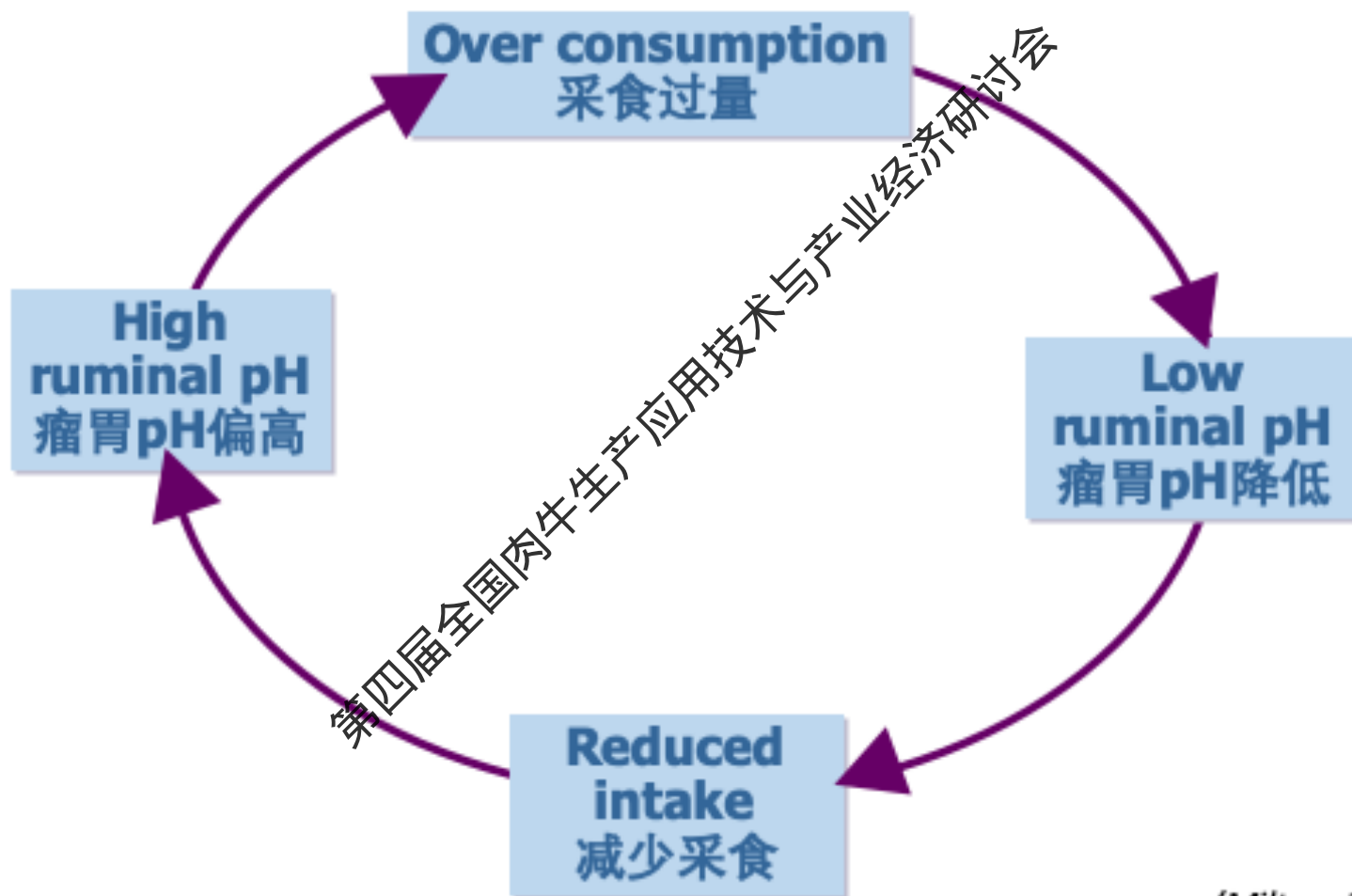
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When things go wrong 问题出在哪里



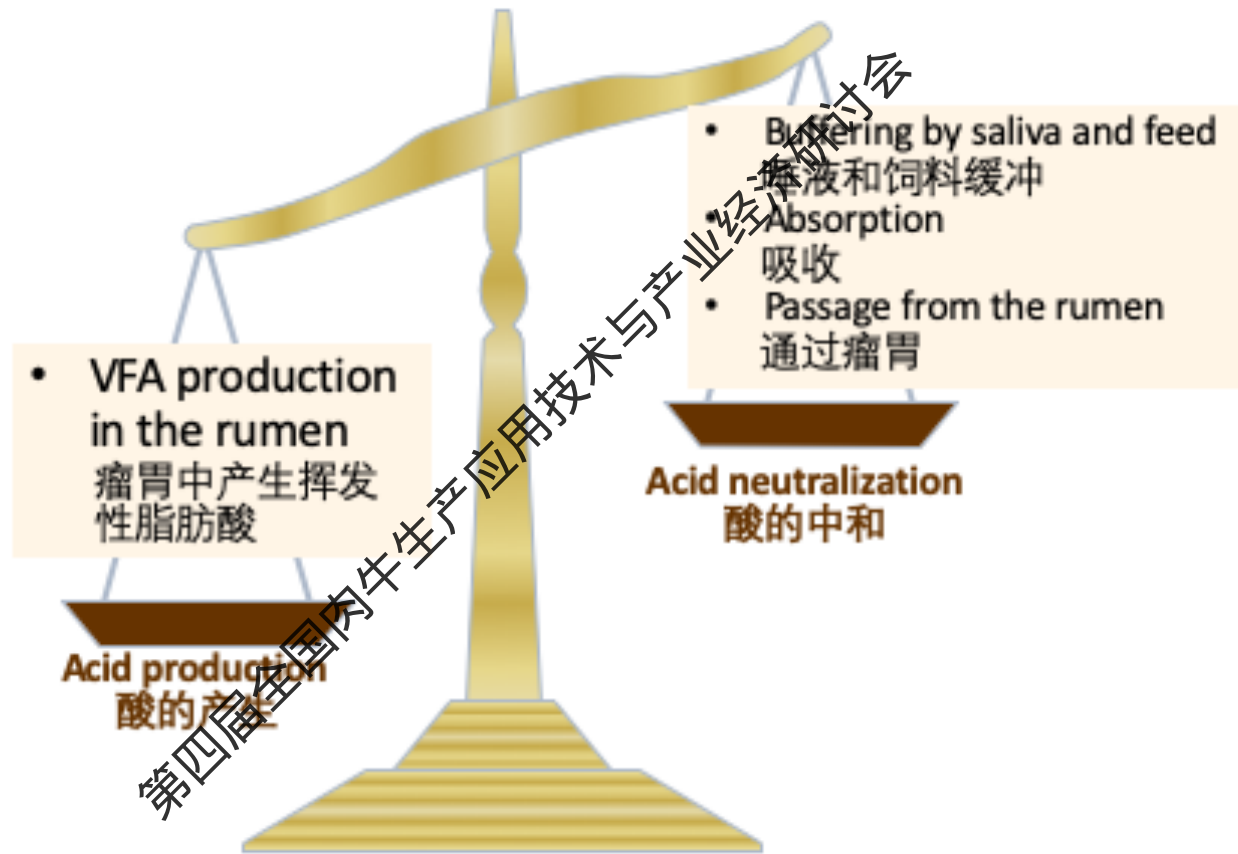


Intake and rumen pH 采食和瘤胃pH



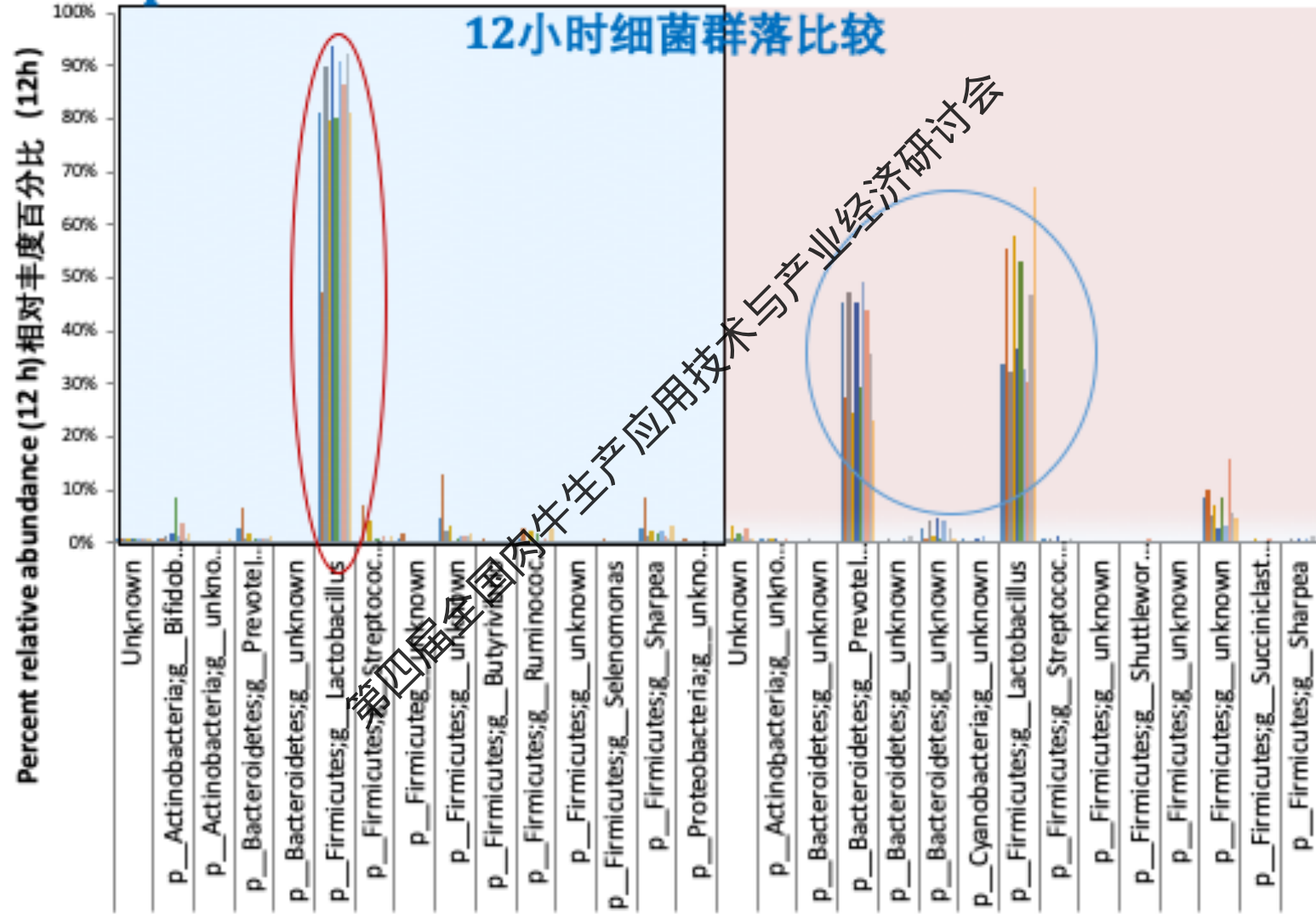
(Milton, 2000)

Subacute Acidosis 亚急性酸中毒

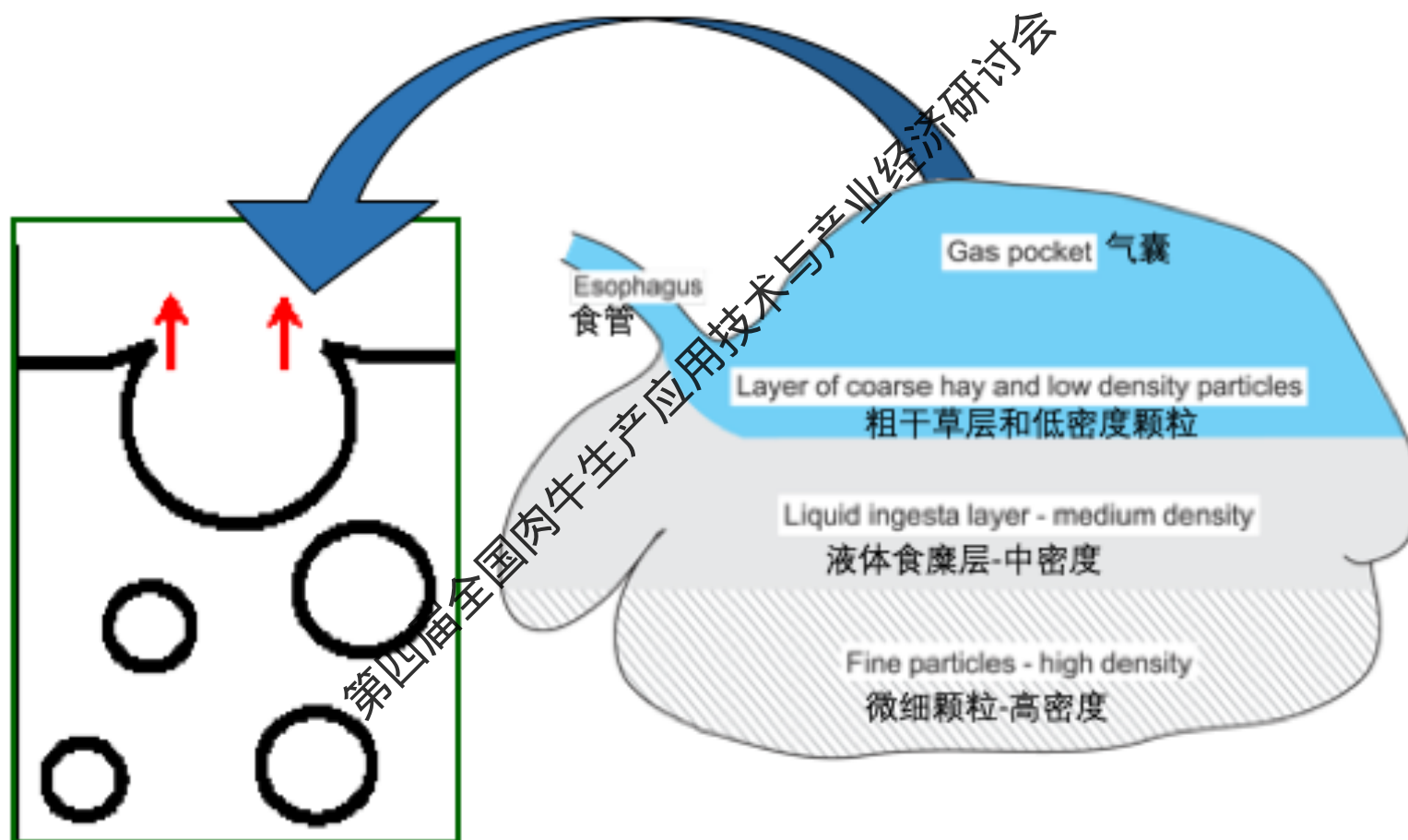


Low vs High Grain 低精料VS高精料:

Comparison between bacterial communities at 12hr

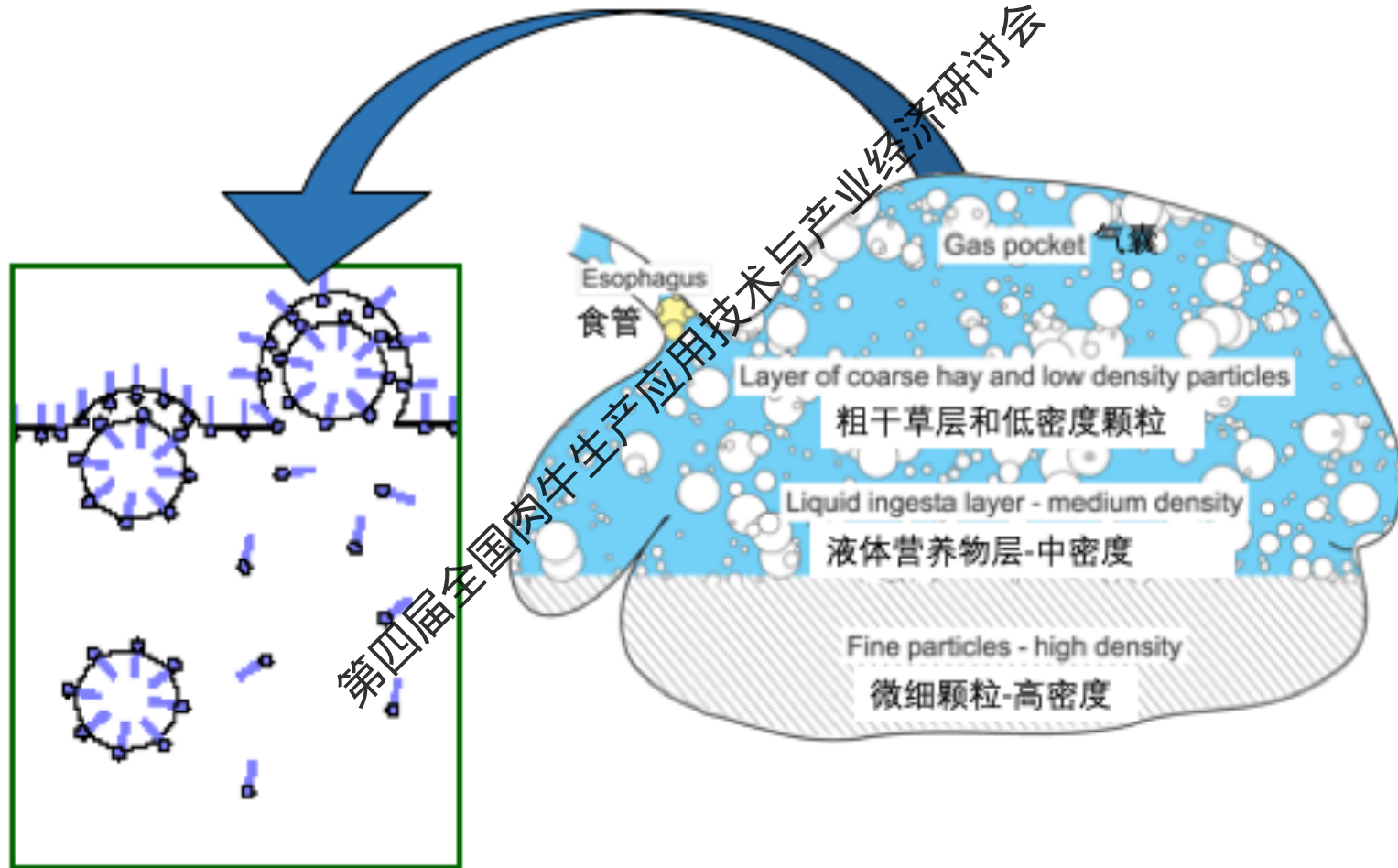


Free gas leads to a belch 游离气体导致打嗝

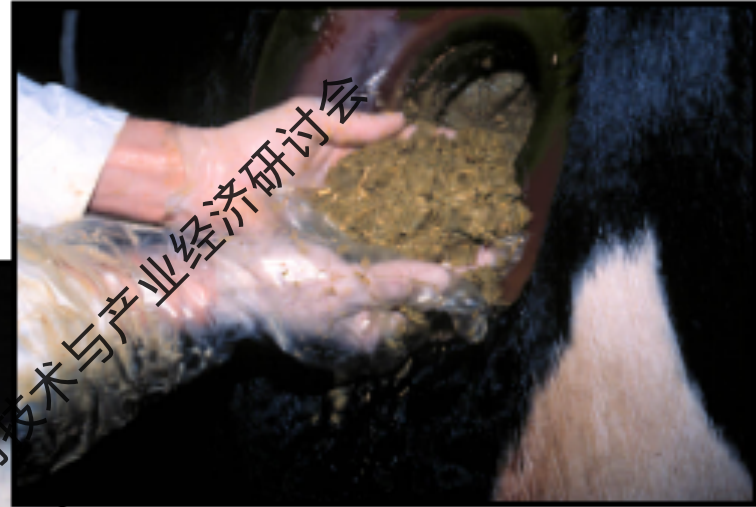


Stabilized froth leads to bloat

稳定的泡沫会导致瘤胃臌胀



Feedlot Bloat肥育场瘤胃鼓气



Bacteria slime - plant proteins stabilize bubbles

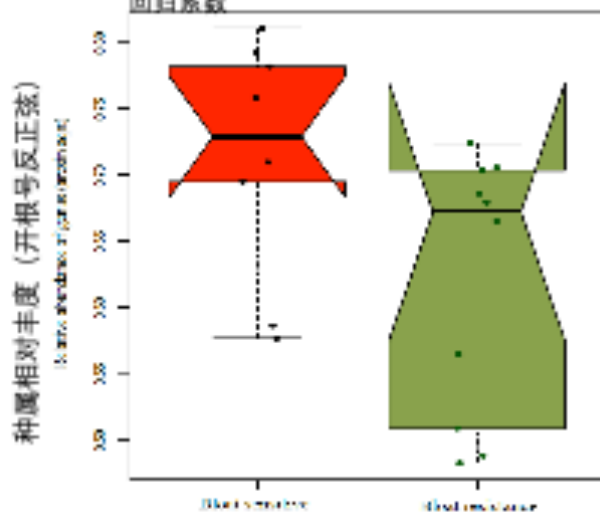
细菌粘液-植物蛋白使泡沫稳定



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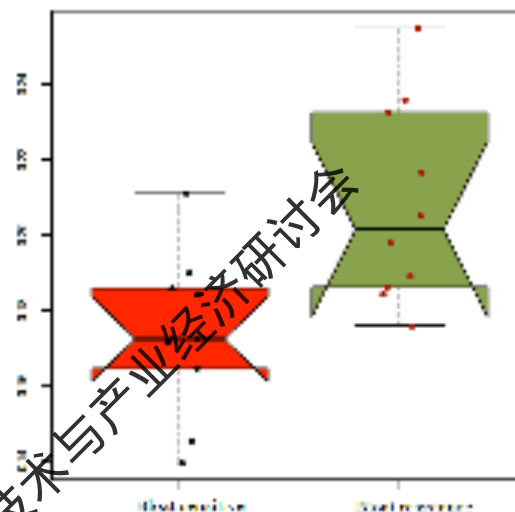
普氏菌属(拟杆菌) *Prevotella* (Bacteroidetes)

(Regression coefficient = -0.057, SD = 0.026, p = 0.044, q = 0.022)



Unclassified Ruminococcaceae (Firmicutes)

(Regression coefficient = 0.023, SD = 0.011, p = 0.016, q = 0.045)

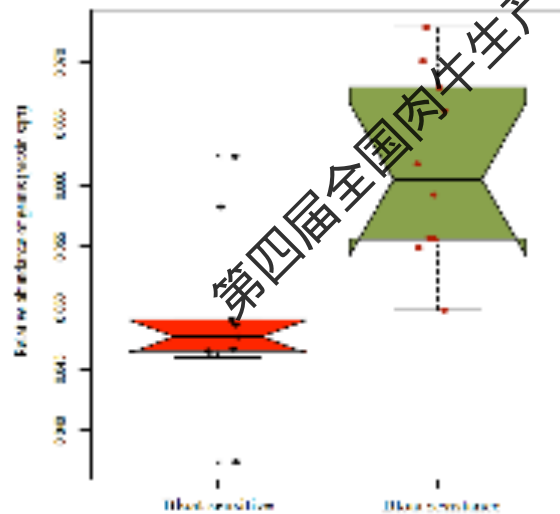


未分类瘤胃菌科
(厚壁菌门)

未分类梭菌属
(厚壁菌门)

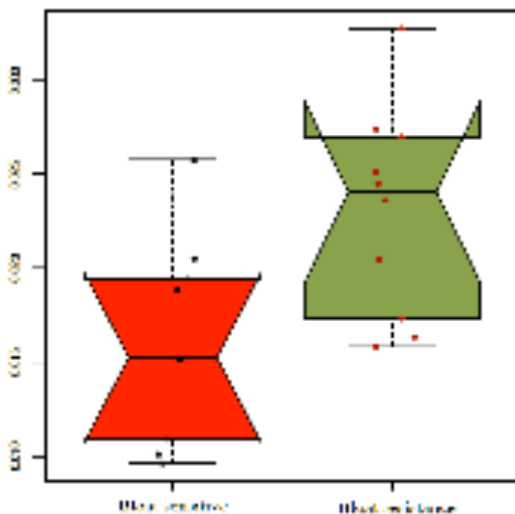
Unclassified Clostridiales (Firmicutes)

(Regression coefficient = 0.017, SD = 0.003, p = 0.002, q = 0.004)



Bulidia (Firmicutes)

(Regression coefficient = 0.007, SD = 0.002, p = 0.001, q = 0.01)



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Conclusions结论

- Understanding the rumen microbiome is the key to proper nutrition and optimizing production efficiency
了解瘤胃微生物是合理调节营养和优化生产效率的关键
- Diet is the primary factor that influences the microbiome
饲料是影响微生物群系的主要因素
- Host animal exerts some control (specific to some microbial groups)
宿主动物会进行某些调节（特指某些微生物群）
- Link to efficiency – low diversity/redundancy
与效率有关—多样性低/数量少
- Early life events – persistency later in life
幼龄时出现状况—会在生长后期持续产生影响
- Post-rumen microbiome
瘤胃后肠道微生物菌群

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Agriculture and
Agri-Food Canada

Agriculture et
Agroalimentaire Canada

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FUNDING



SAGES

(Sustainable Agriculture Environmental Systems)



Thank you - Questions?
感谢聆听—提问？

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View of Chief Mountain in the Canadian Rockies near Waterton, AB ~1.5 hr from Lethbridge
阿尔伯塔省Waterton附近看到的加拿大落基山脉主峰，离莱斯布里奇1.5小时车程