Muscle Energy Metabolism, Growth and Meat Quality

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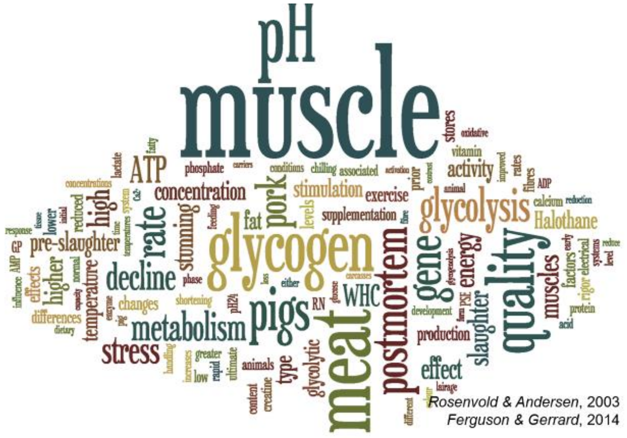
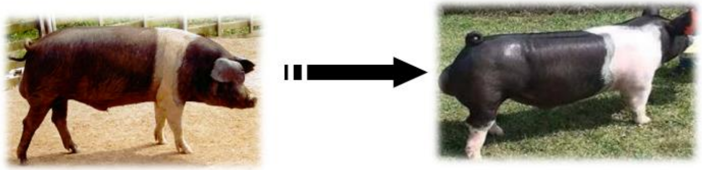
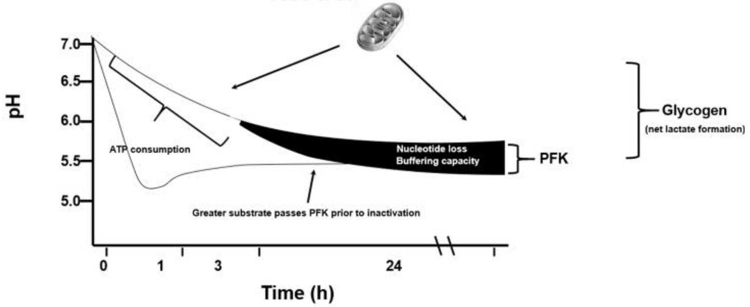
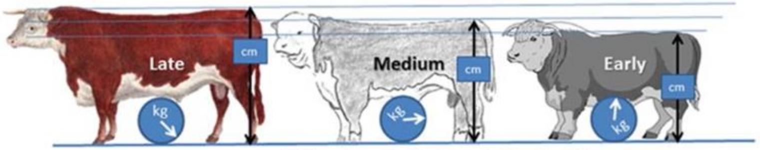
Programa Nacional de Carne y Lana, INIA Tacuarembó, Ruta 5, km 386, Tacuarembó, URUGUAY



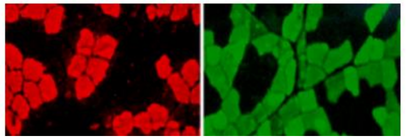


Model





Different maturity types in beef cattle

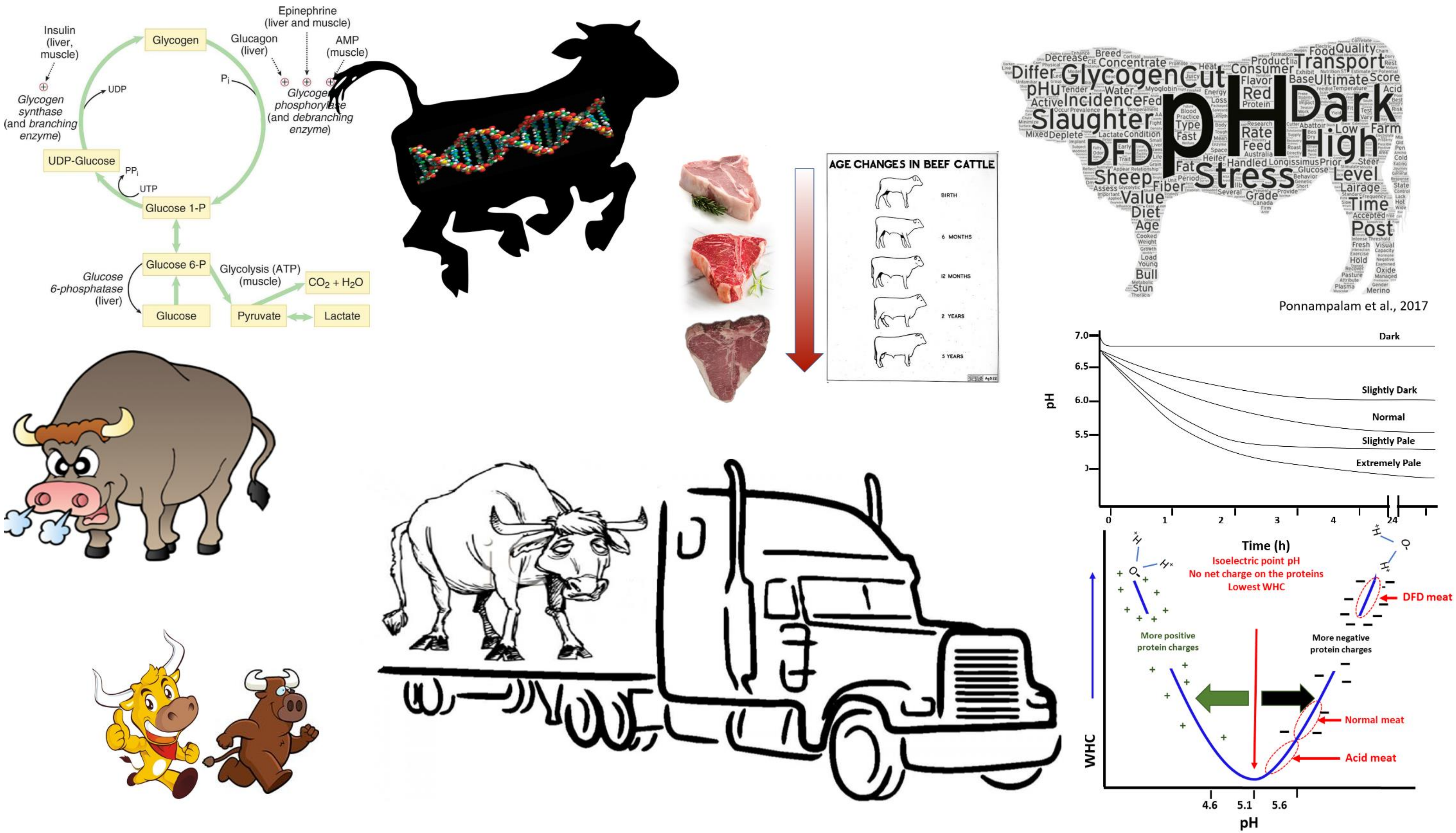


<u>15%</u> of all retail beef does not meet consumer's standard for color

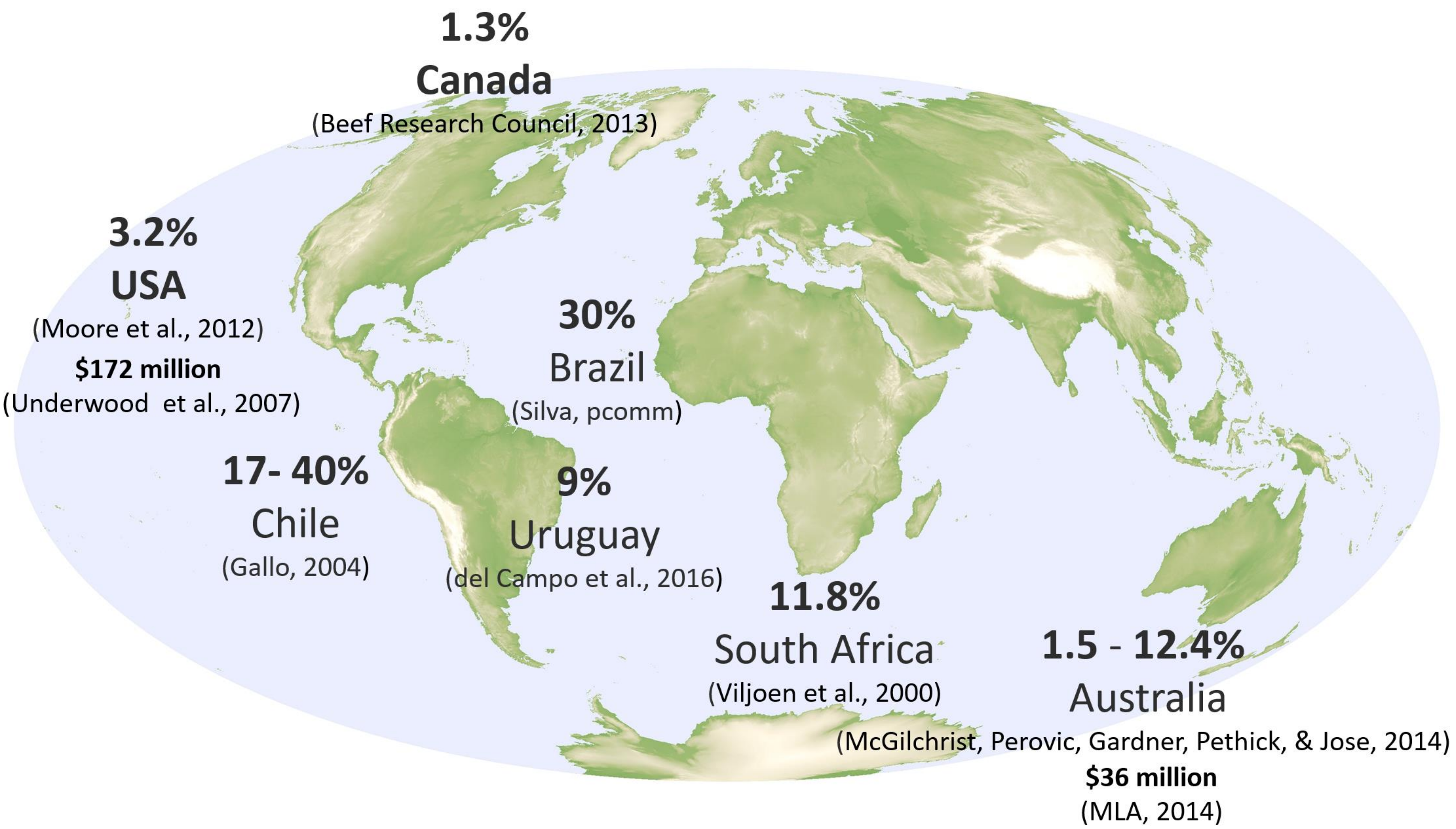
(Smith et al., 2000; Kilinger et al., 2004)

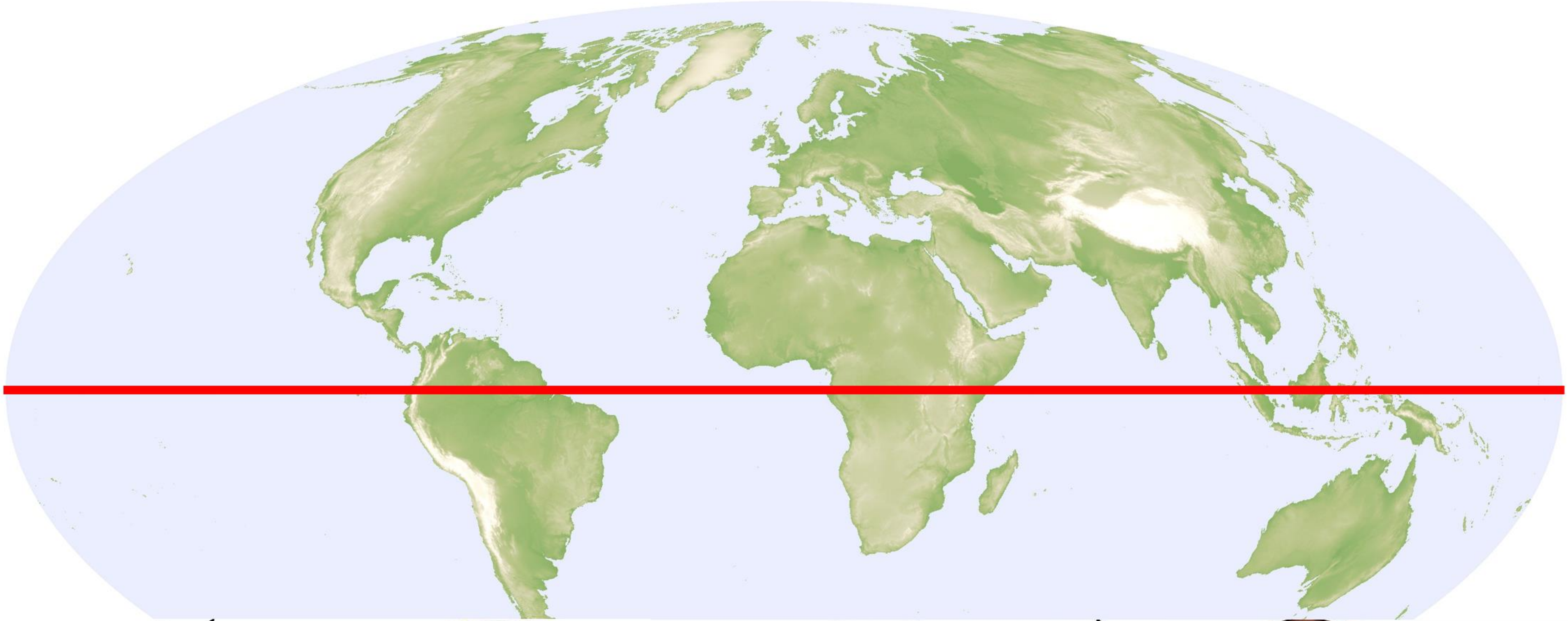
<u>$1 Billion</u> economic loss to the US beef industry annually

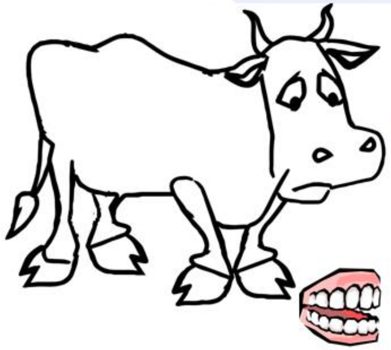
(Smith et al., 2000)

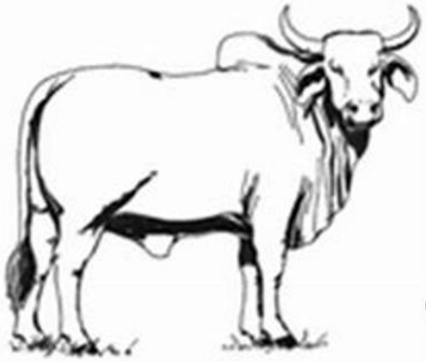


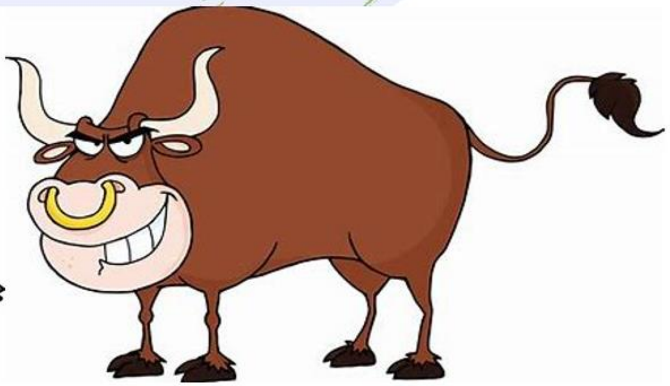
Insulin (liver, muscle)
Glycogen
Glucagon (liver)
Epinephrine (liver and muscle)
AMP (muscle)
UDP
P_i
Glycogen synthase (and branching enzyme)
Glycogen phosphorylase (and debranching enzyme)
UDP-Glucose
PP_i
UTP
Glucose 1-P
Glucose 6-P
Glycolysis (ATP) (muscle)
$CO_2 + H_2O$
Glucose 6-phosphatase (liver)
Glucose
Pyruvate
Lactate
AGE CHANGES IN BEEF CATTLE
BIRTH
6 MONTHS
12 MONTHS
2 YEARS
5 YEARS
Ponnampalam et al., 2017
pH
Dark
Slightly Dark
Normal
Slightly Pale
Extremely Pale
Time (h)
Isoelectric point pH
No net charge on the proteins
Lowest WHC
More positive protein charges
More negative protein charges
DFD meat
Normal meat
Acid meat
WHC
4.6
5.1
5.6


1.3%
Canada
(Beef Research Council, 2013)
3.2%
USA
(Moore et al., 2012)
$172 million
(Underwood et al., 2007)
30%
Brazil
(Silva, pcomm)
17- 40%
Chile
(Gallo, 2004)
9%
Uruguay
(del Campo et al., 2016)
11.8%
South Africa
(Viljoen et al., 2000)
1.5 - 12.4%
Australia
(McGilchrist, Perovic, Gardner, Pethick, & Jose, 2014)
$36 million
(MLA, 2014)

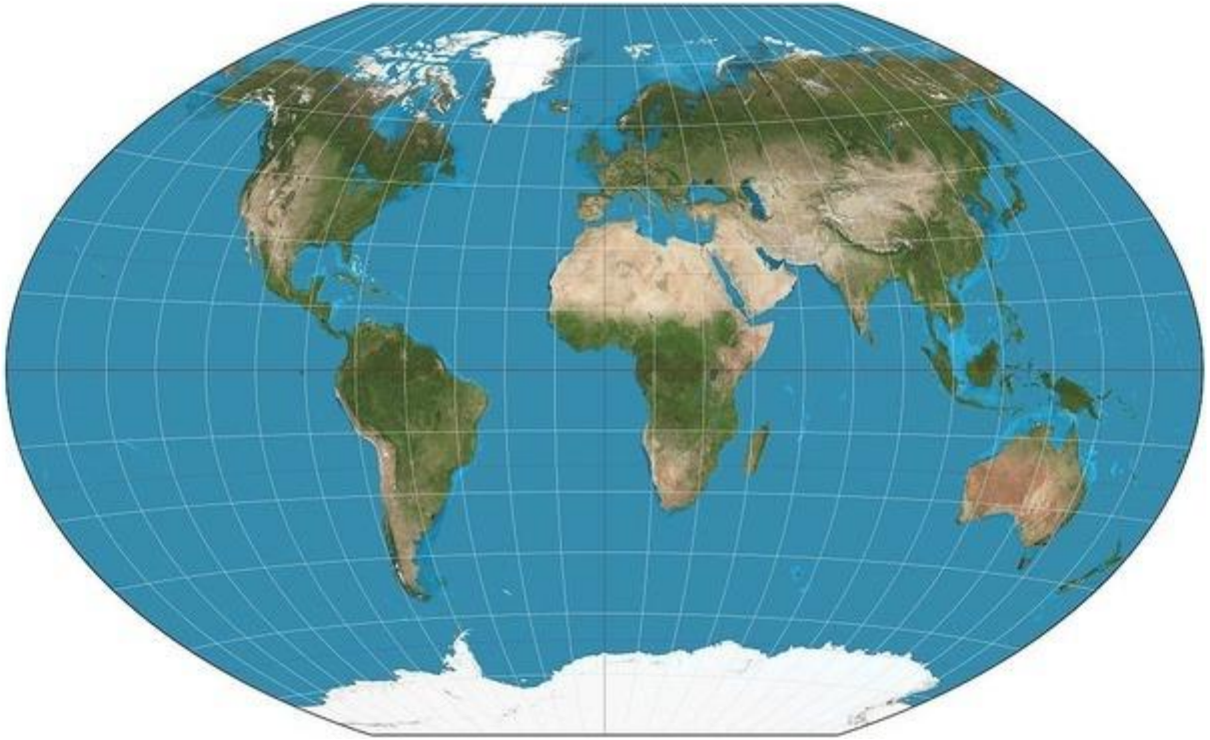




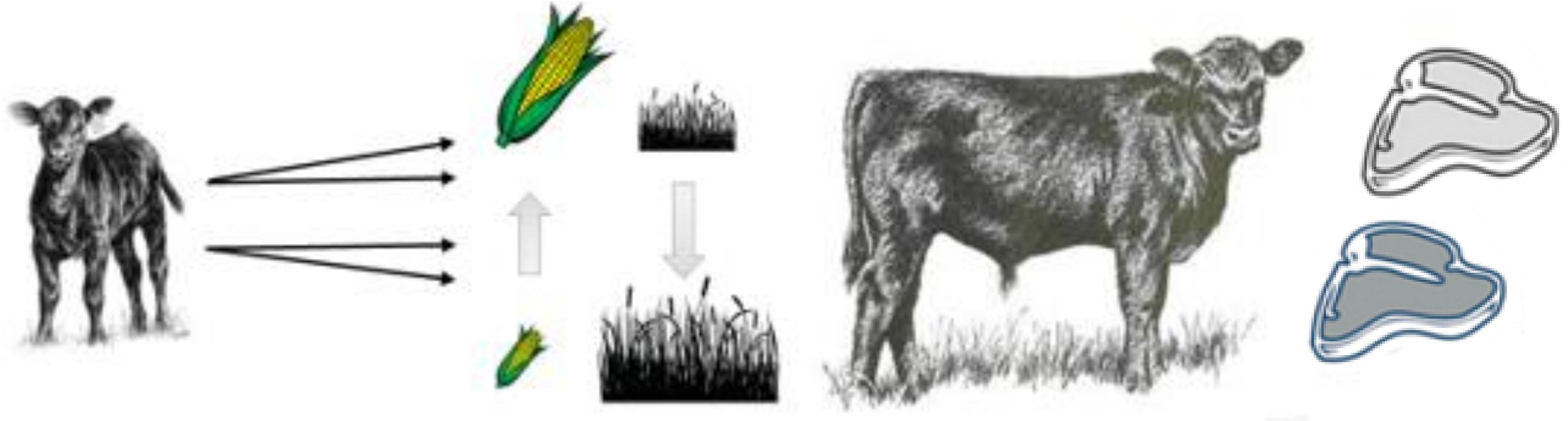




Intensive



Extensive



Hypothesis

Dark beef <u>also</u> results from different rearing paradigms, altering muscle characteristics, postmortem metabolism and ultimate color development.

Meat and Muscle Biology™

Postweaning Exposure to High Concentrates versus Forages Alters Marbling Deposition and Lipid Metabolism in Steers[1]

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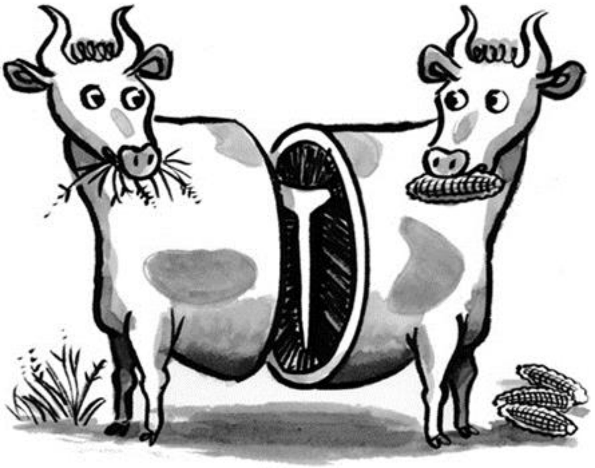
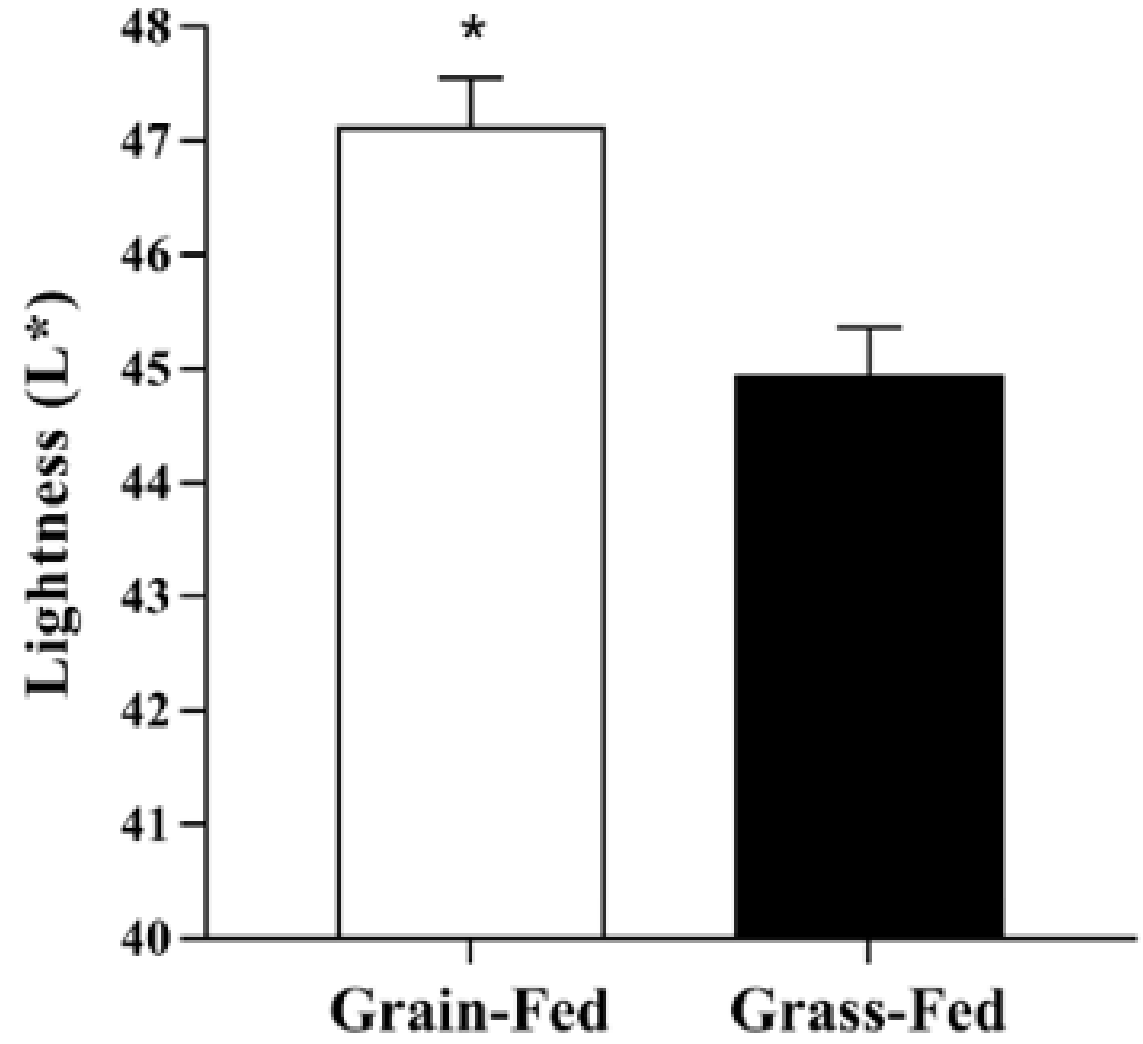
Study and Samples

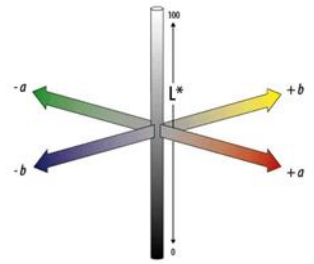
Table 1. Live performance of steers fed a high-concentrate based diet (CONC) or grazed high-quality forages (FOR) for 127 d post weaning

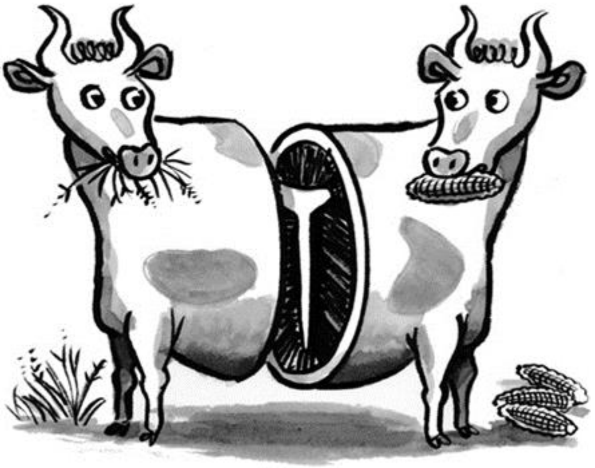
Item	CONC	FOR	SEM	*P*-value
Initial body weight, kg	260	262	7.1	0.825
Shrunk final body weight, kg	422	338	10.4	< 0.001
Average daily gain, kg/d	1.36	0.68	0.058	< 0.001
Dry matter intake, kg/d	7.82	–	–	–
Feed efficiency, feed:gain	5.44	–	–	–
Hot carcass weight, kg	248	179	6.0	< 0.001
Dressing percentage, %	58.1	52.9	0.57	< 0.001
Ribeye area, cm^2	72.3	57.9	2.44	< 0.001
Fat thickness, cm	0.45	0.14	0.052	< 0.001
Kidney, pelvic, heart fat, %	1.77	0.75	0.200	0.0004
Yield grade	1.79	1.51	0.125	0.228
Skeletal maturity (100 = A)	152	149	2.17	0.342
Marbling score (500 = small)	548	340	14.4	< 0.001
Percent Choice	80	0	9.4	< 0.0001

Grain-Fed cattle possess a lighter lean

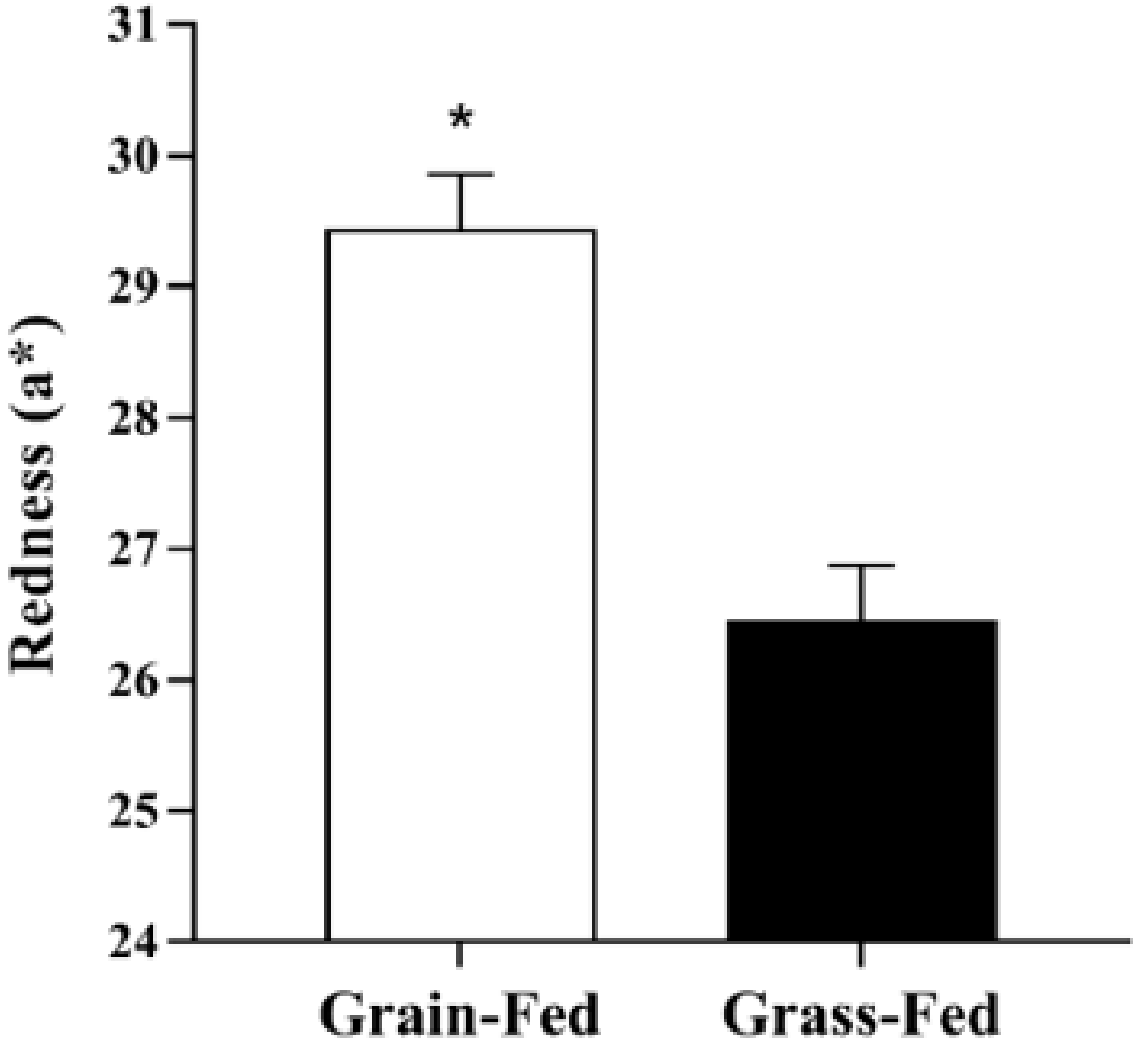


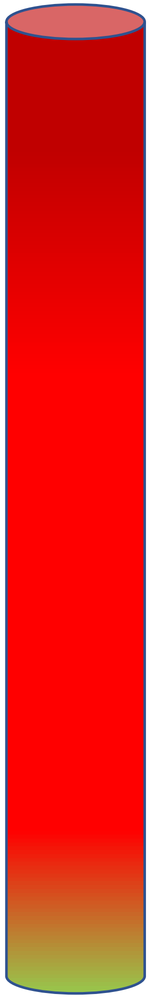


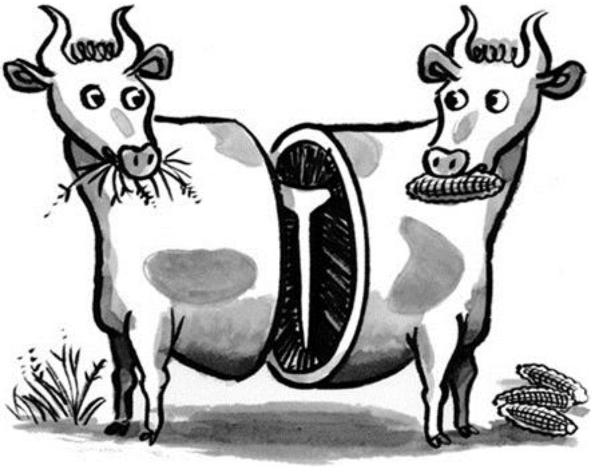


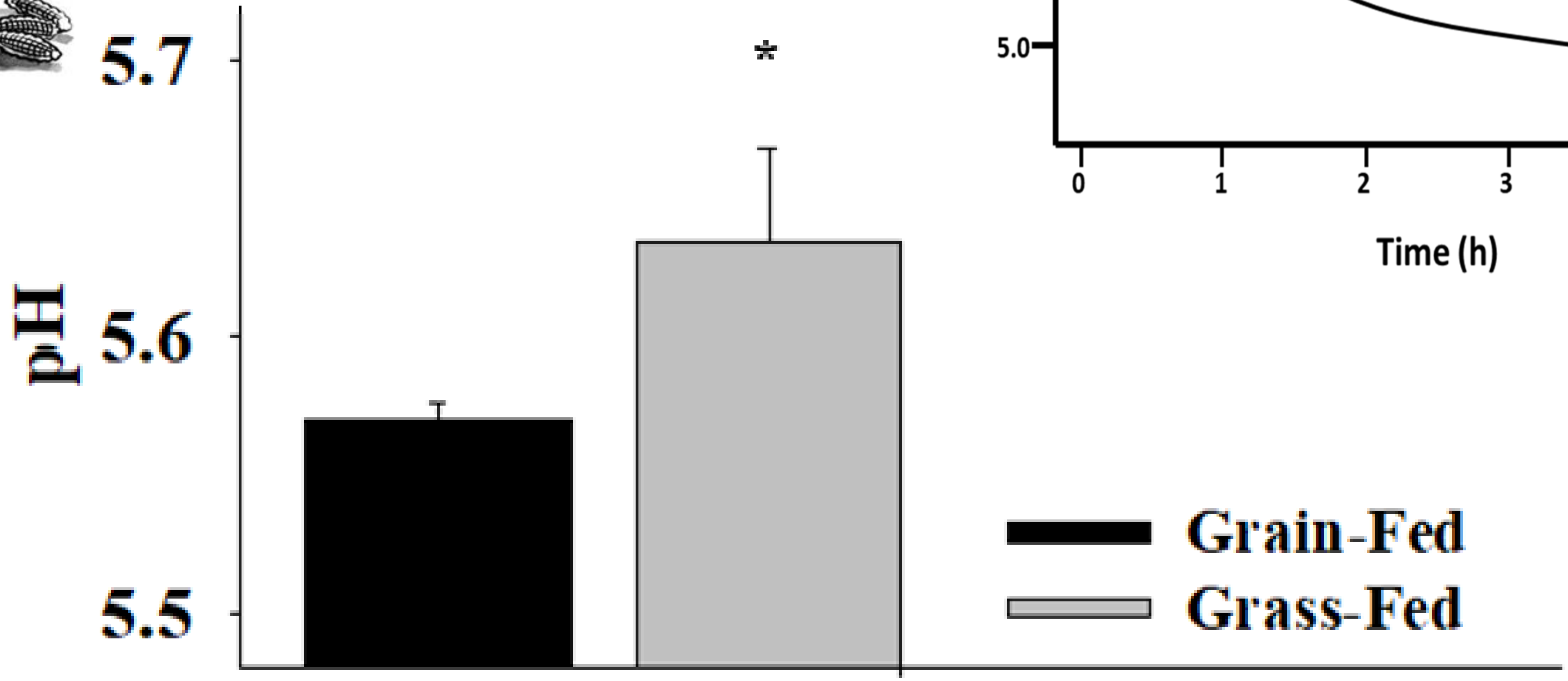


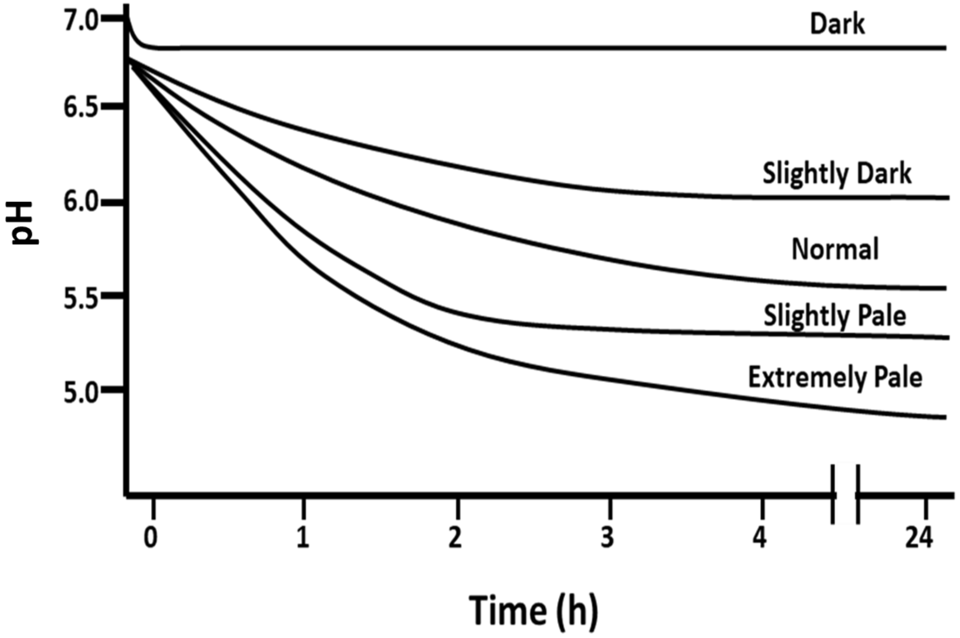
Grain-Fed cattle have less red lean



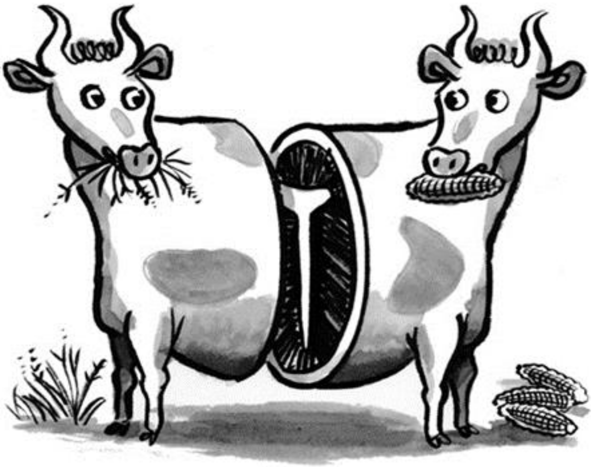


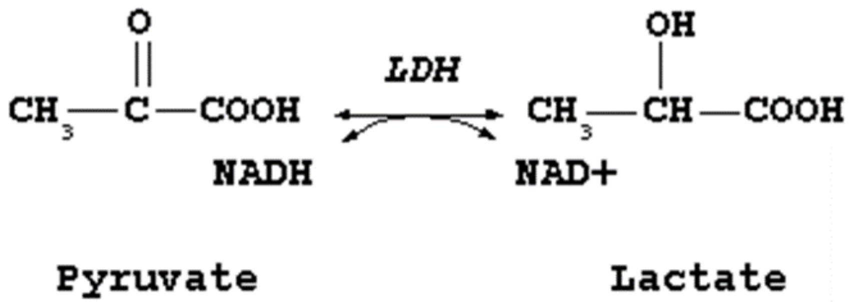




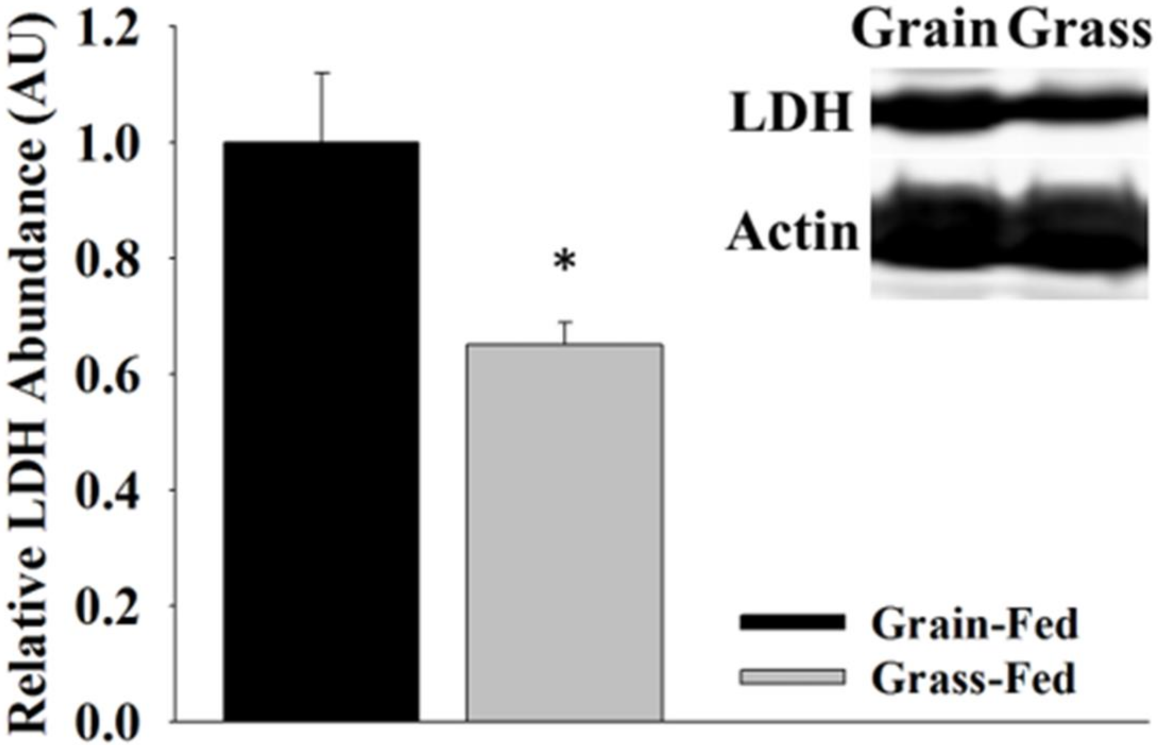


pH of lean from Grass-Fed cattle is NOT ALWAYS high

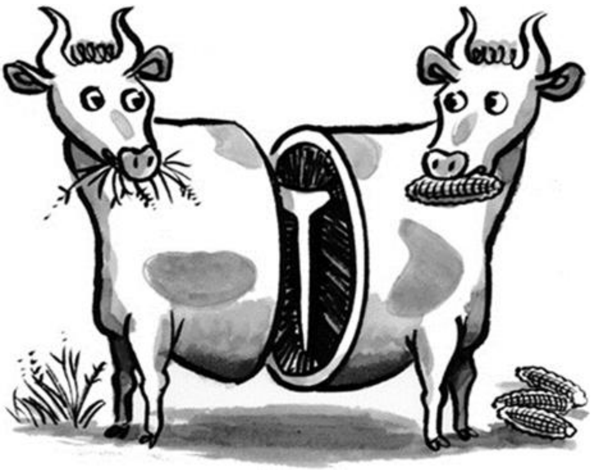


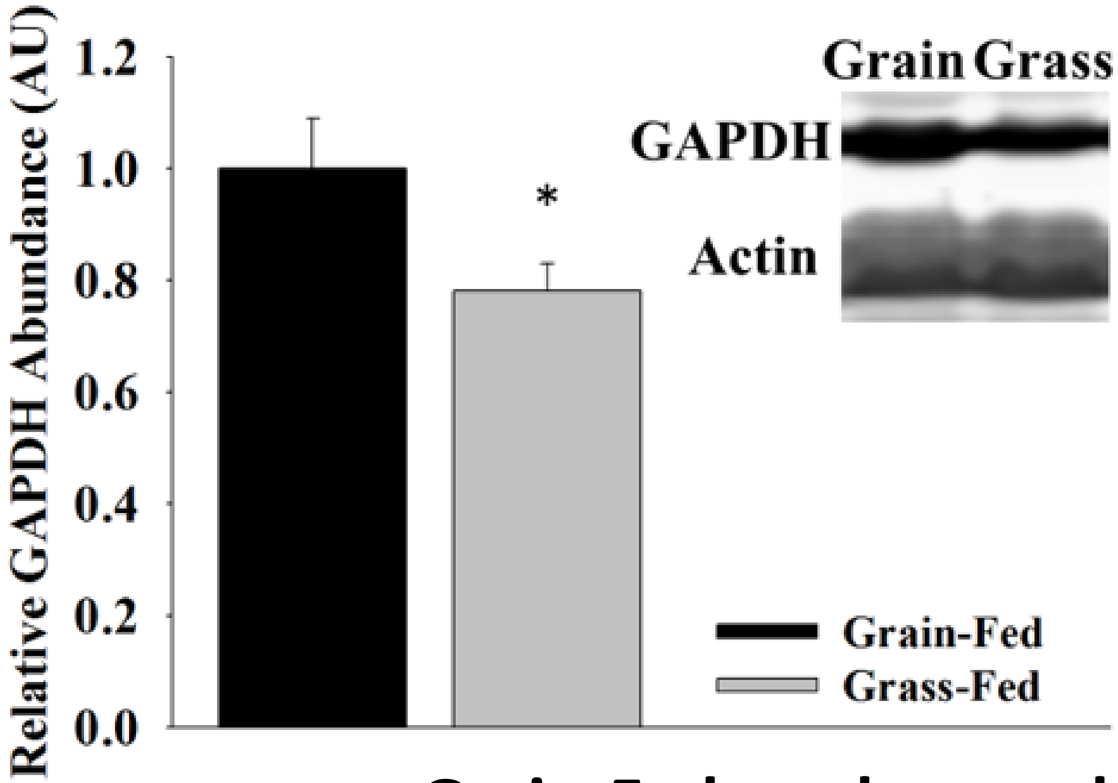


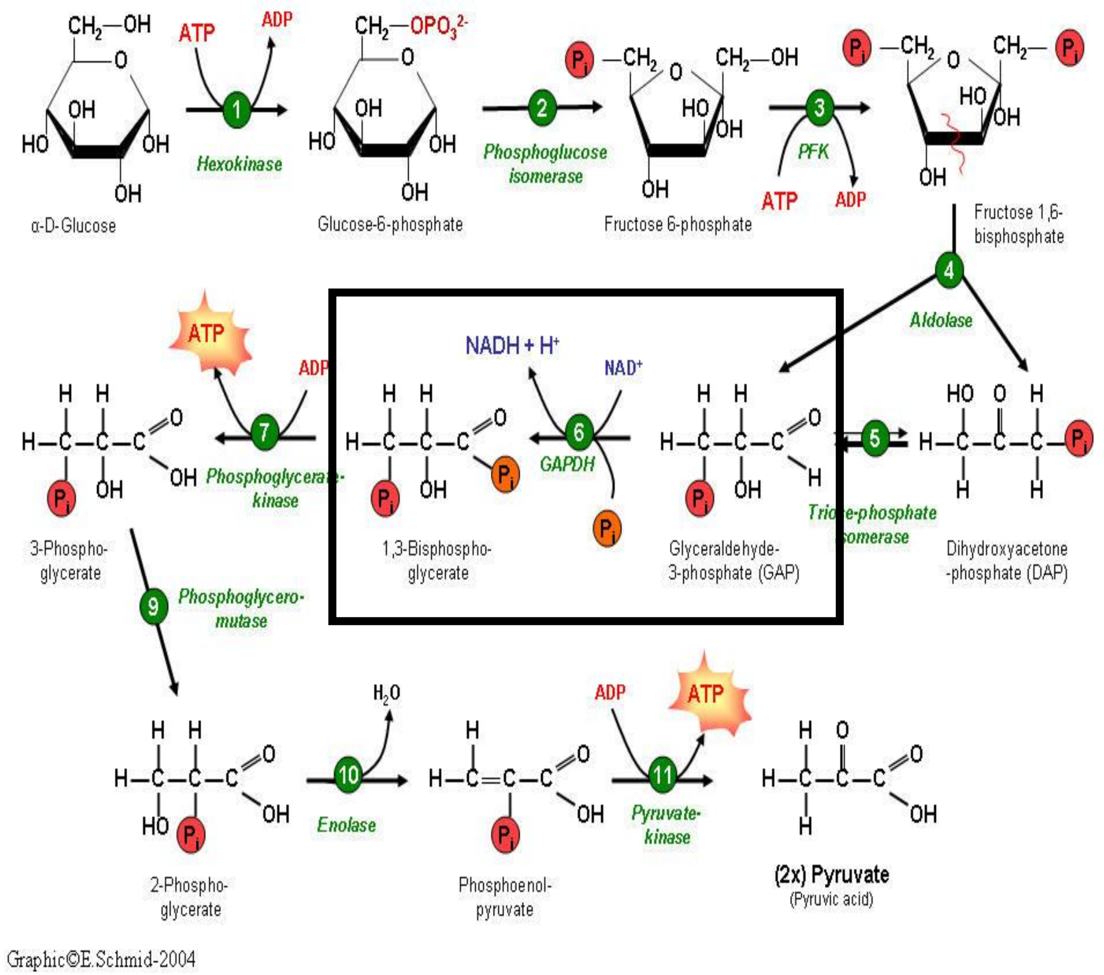
O
OH
LDH
CH_3—C—COOH
CH_3—CH—COOH
NADH
NAD+
Pyruvate
Lactate



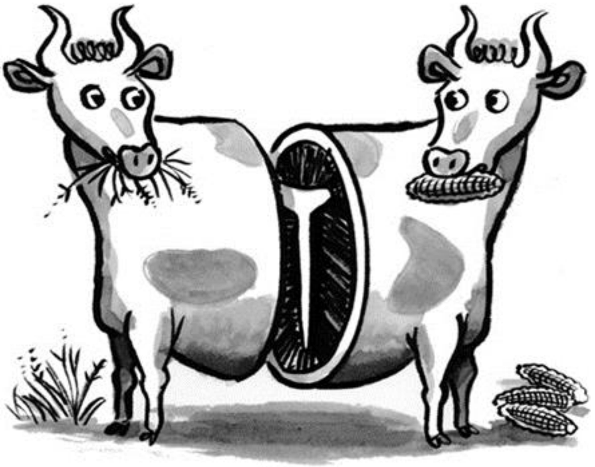
Relative LDH Abundance (AU)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
*
Grain Grass
LDH
Actin
Grain-Fed
Grass-Fed

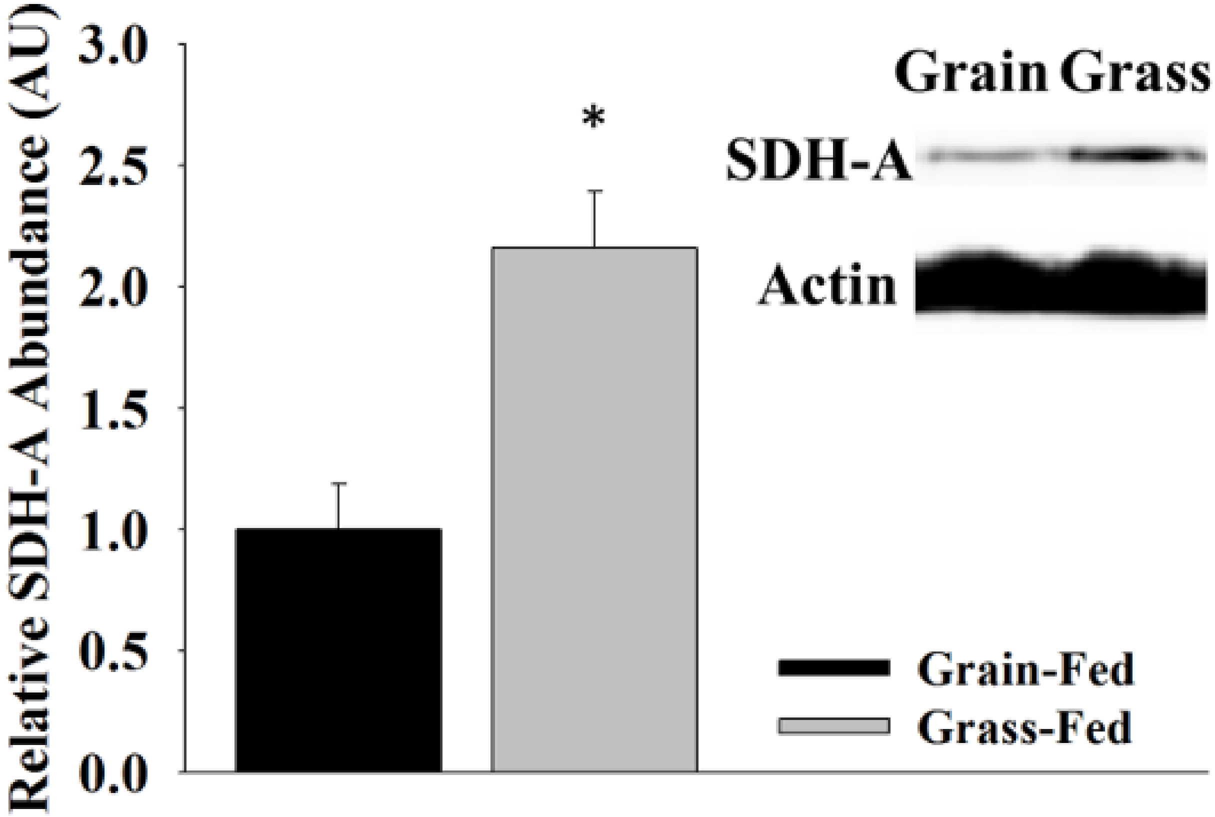


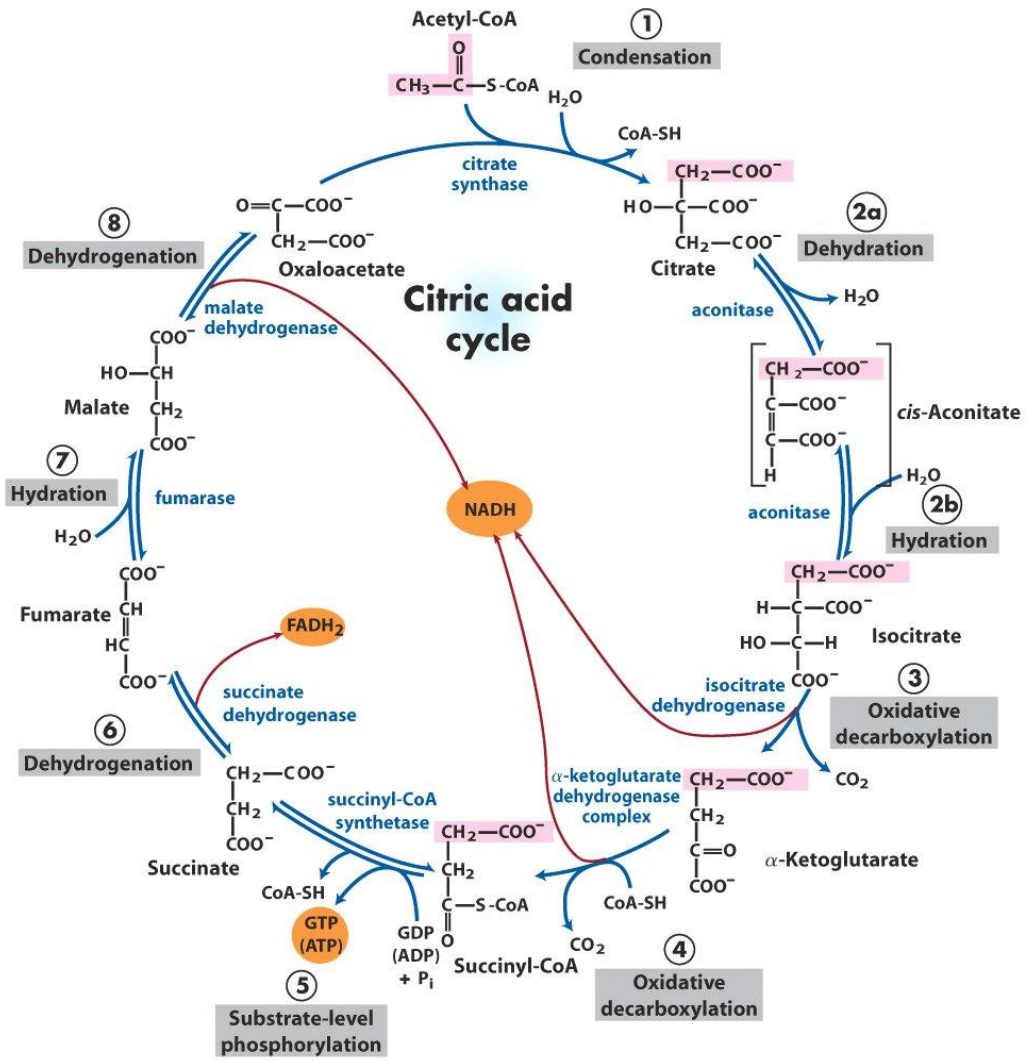




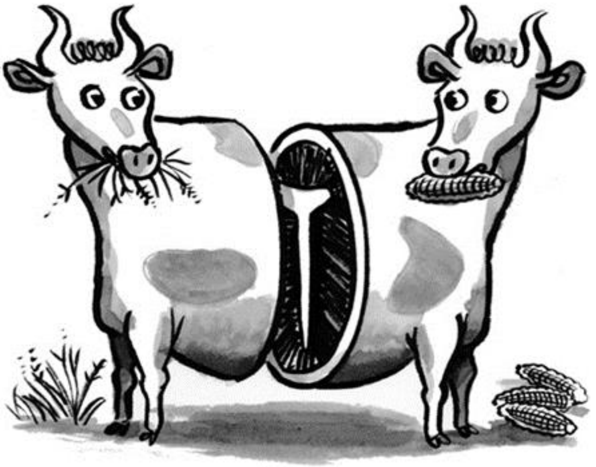
Grain-Fed cattle muscle is more glycolytic

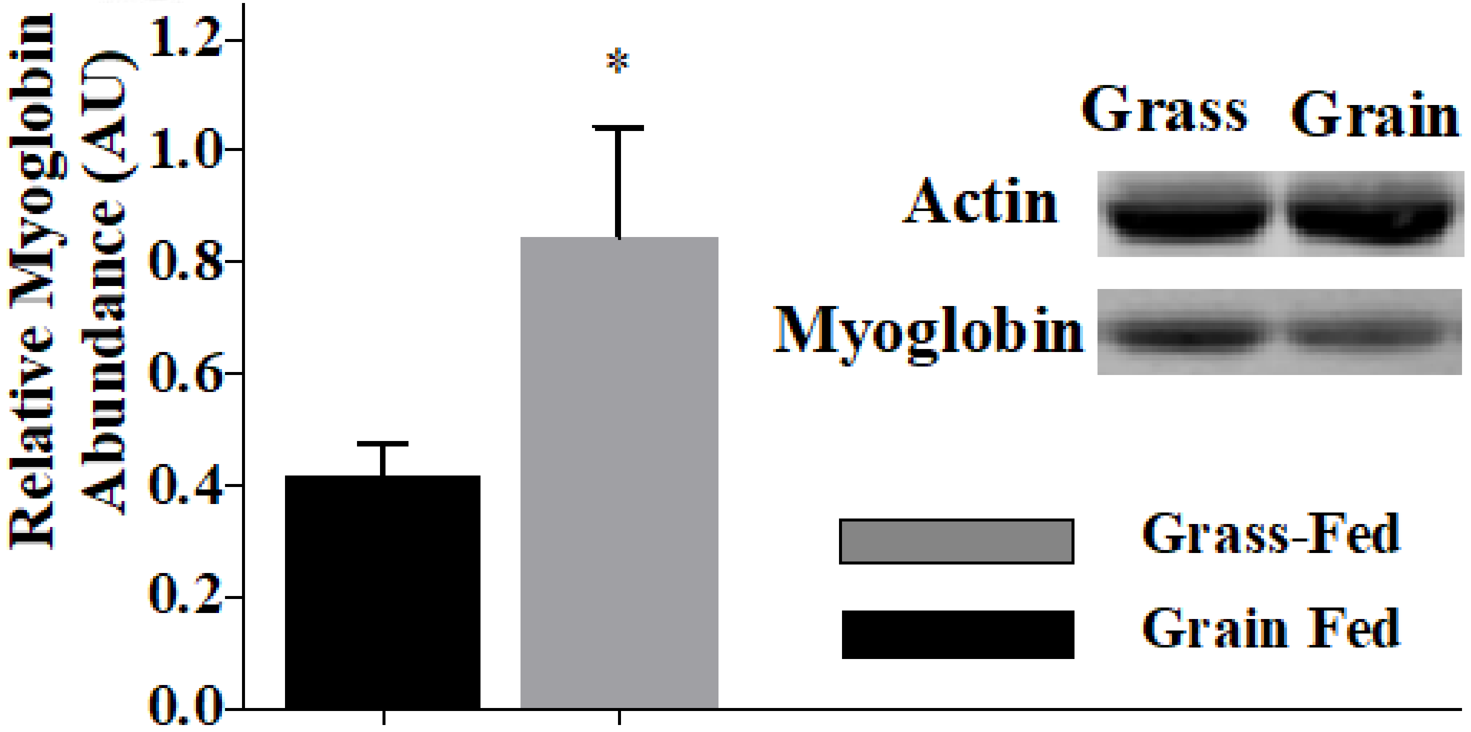


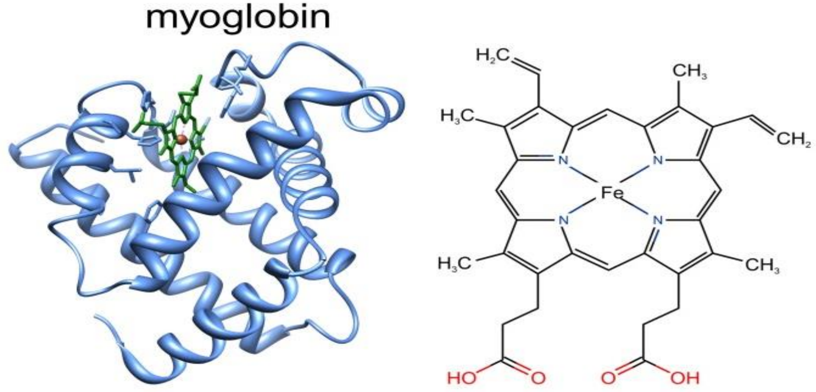


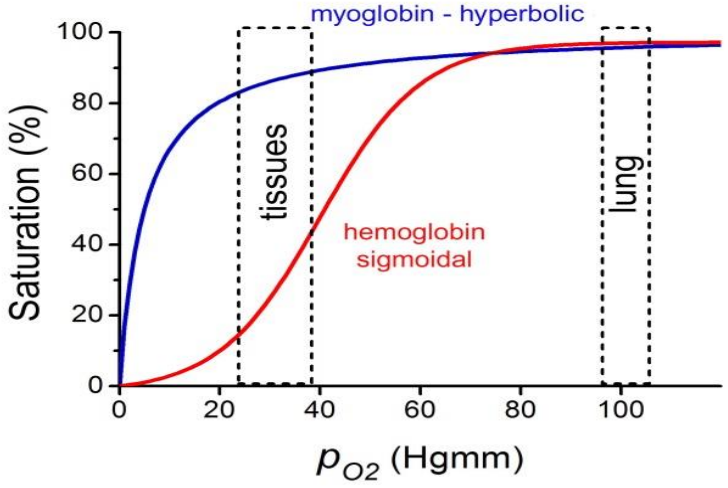


Grass-Fed cattle have oxidative muscle

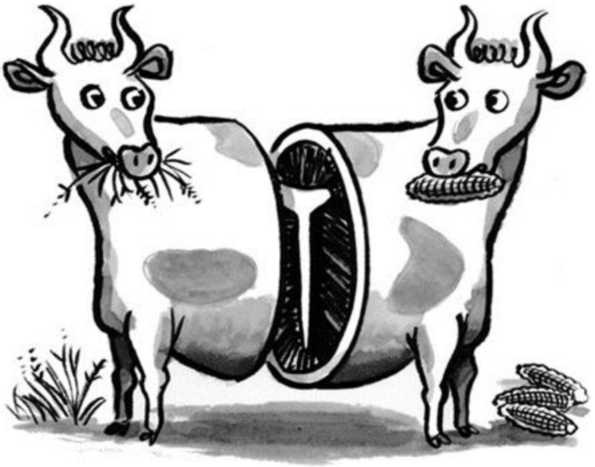




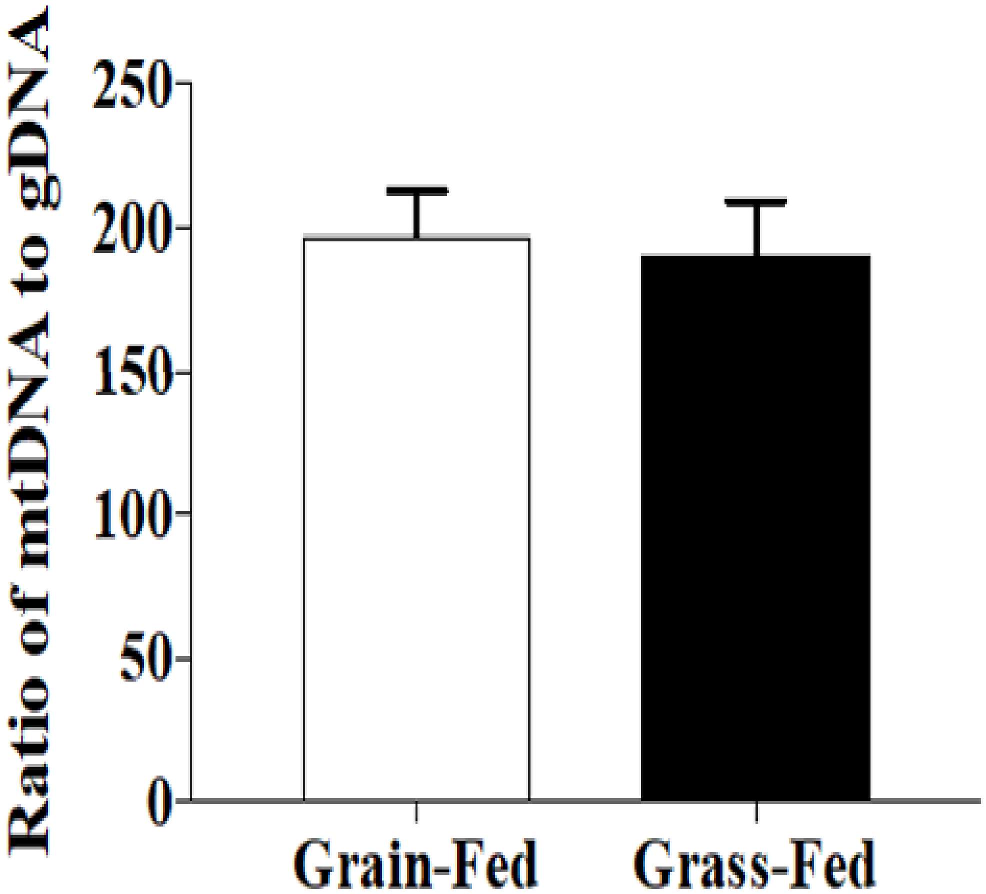


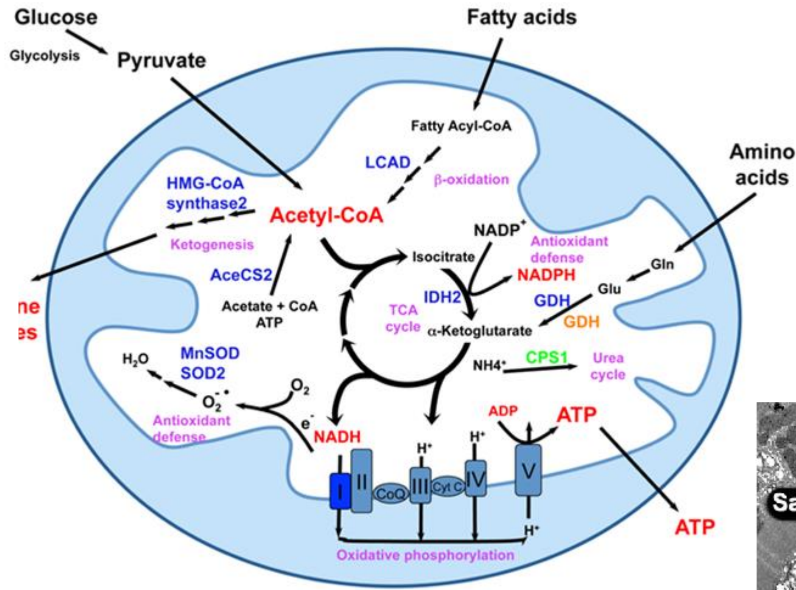


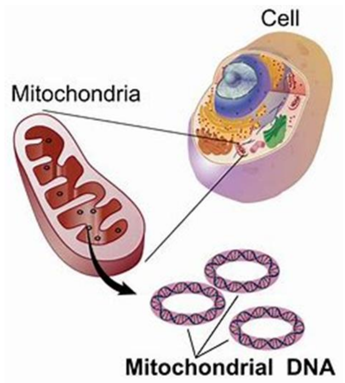
Grass-Fed cattle have increased abundance of myoglobin

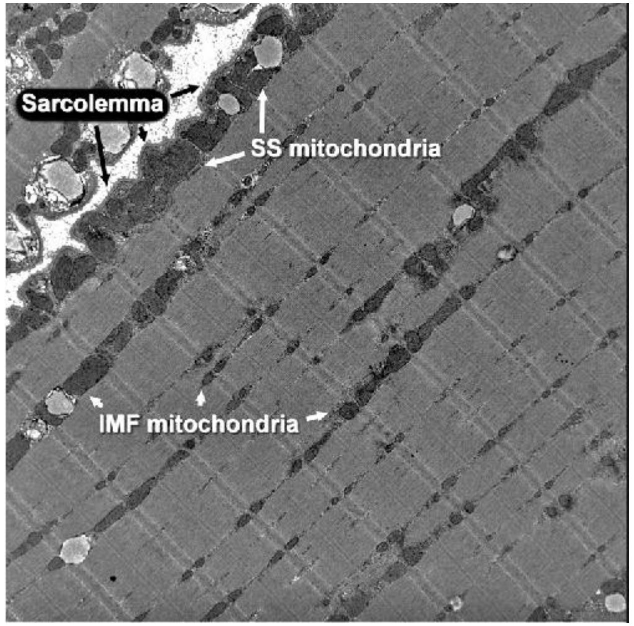


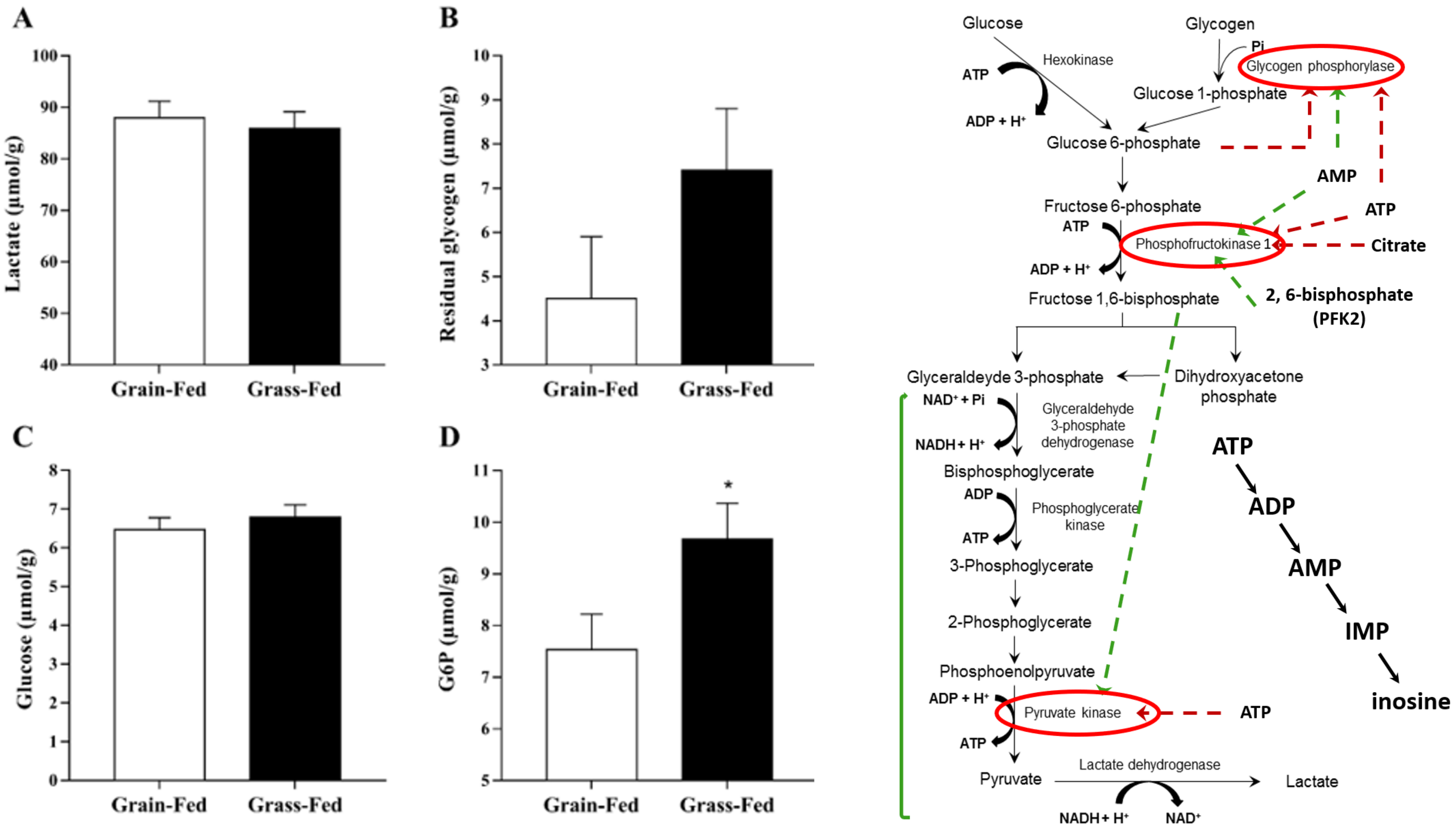
Mitochondrial abundance does not differ



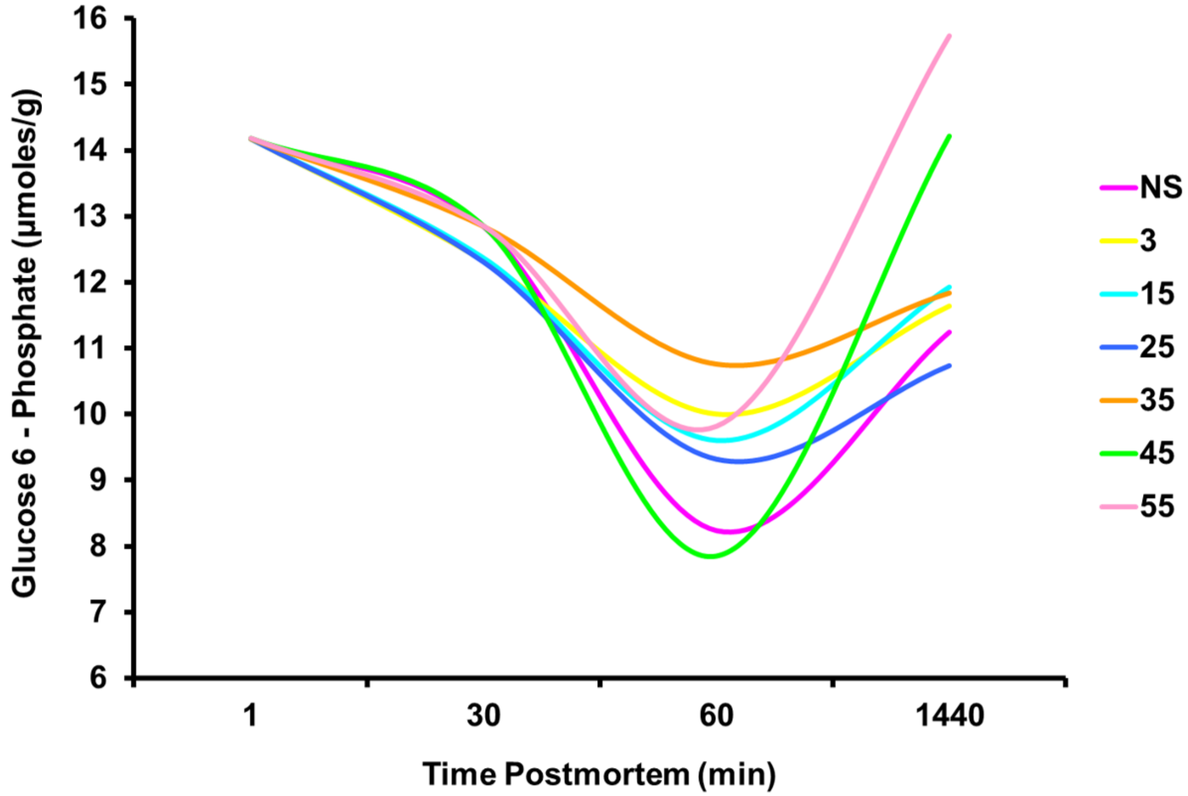




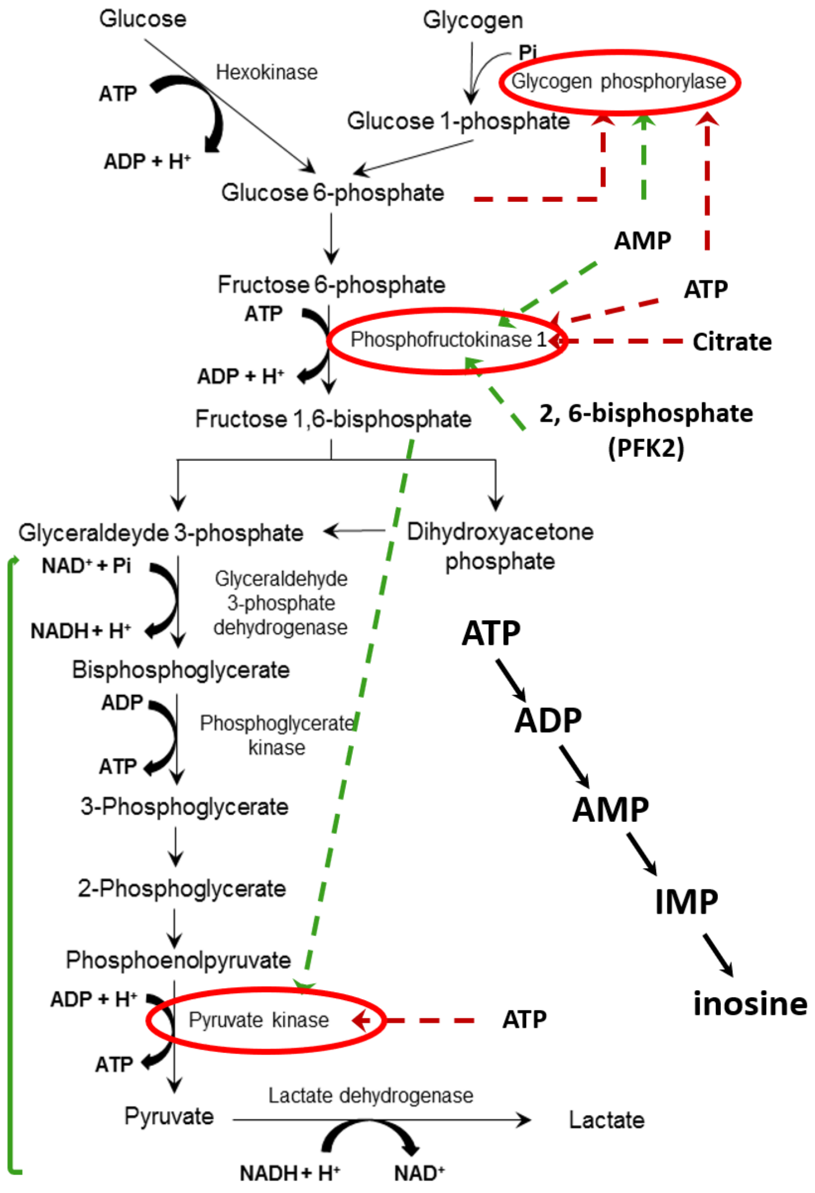




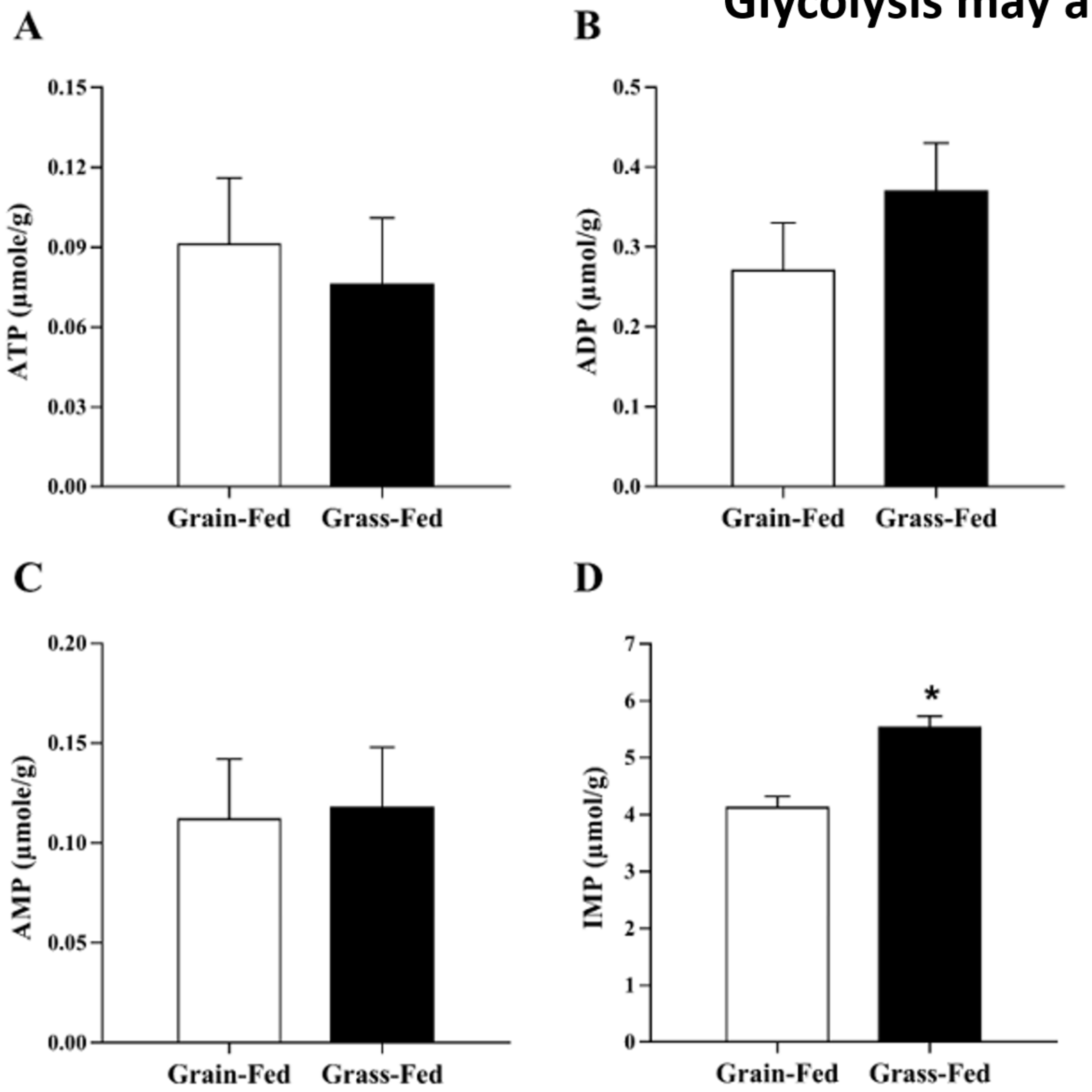
A
Lactate (μmol/g)
100
90
80
70
60
50
40
Grain-Fed
Grass-Fed
B
Residual glycogen (μmol/g)
10
9
8
7
6
5
4
3
Grain-Fed
Grass-Fed
C
Glucose (μmol/g)
8
7
6
5
4
3
2
1
0
Grain-Fed
Grass-Fed
D
G6P (μmol/g)
11
10
9
8
7
6
5
*
Grain-Fed
Grass-Fed
Glucose
Glycogen
Hexokinase
Pi
Glycogen phosphorylase
ATP
ADP + H⁺
Glucose 1-phosphate
Glucose 6-phosphate
AMP
ATP
Fructose 6-phosphate
ATP
Phosphofructokinase 1
Citrate
ADP + H⁺
Fructose 1,6-bisphosphate
2, 6-bisphosphate
(PFK2)
Glyceraldeyde 3-phosphate
Dihydroxyacetone phosphate
NAD⁺ + Pi
NADH + H⁺
Glyceraldehyde 3-phosphate dehydrogenase
Bisphosphoglycerate
ADP
ATP
Phosphoglycerate kinase
3-Phosphoglycerate
2-Phosphoglycerate
Phosphoenolpyruvate
ADP + H⁺
Pyruvate kinase
ATP
ATP
Pyruvate
Lactate dehydrogenase
Lactate
NADH + H⁺
NAD⁺
ATP
ADP
AMP
IMP
inosine



Hammelman et al., 2002



Glycolysis may arrest sooner in muscle of Grass-Fed cattle



Phosphogen System

$$PCr + ADP \xleftrightarrow{\text{Creatine Kinase}} ATP + Cr$$

$$ATP \xrightarrow{\text{ATPase}} ADP + PO_4^- + H^+$$

Energy Charge

$$2\ ADP \xleftrightarrow{\text{Adenylate Kinase}} ATP + AMP \xleftrightarrow{\text{AMP Deaminase}} IMP + NH_4^+$$

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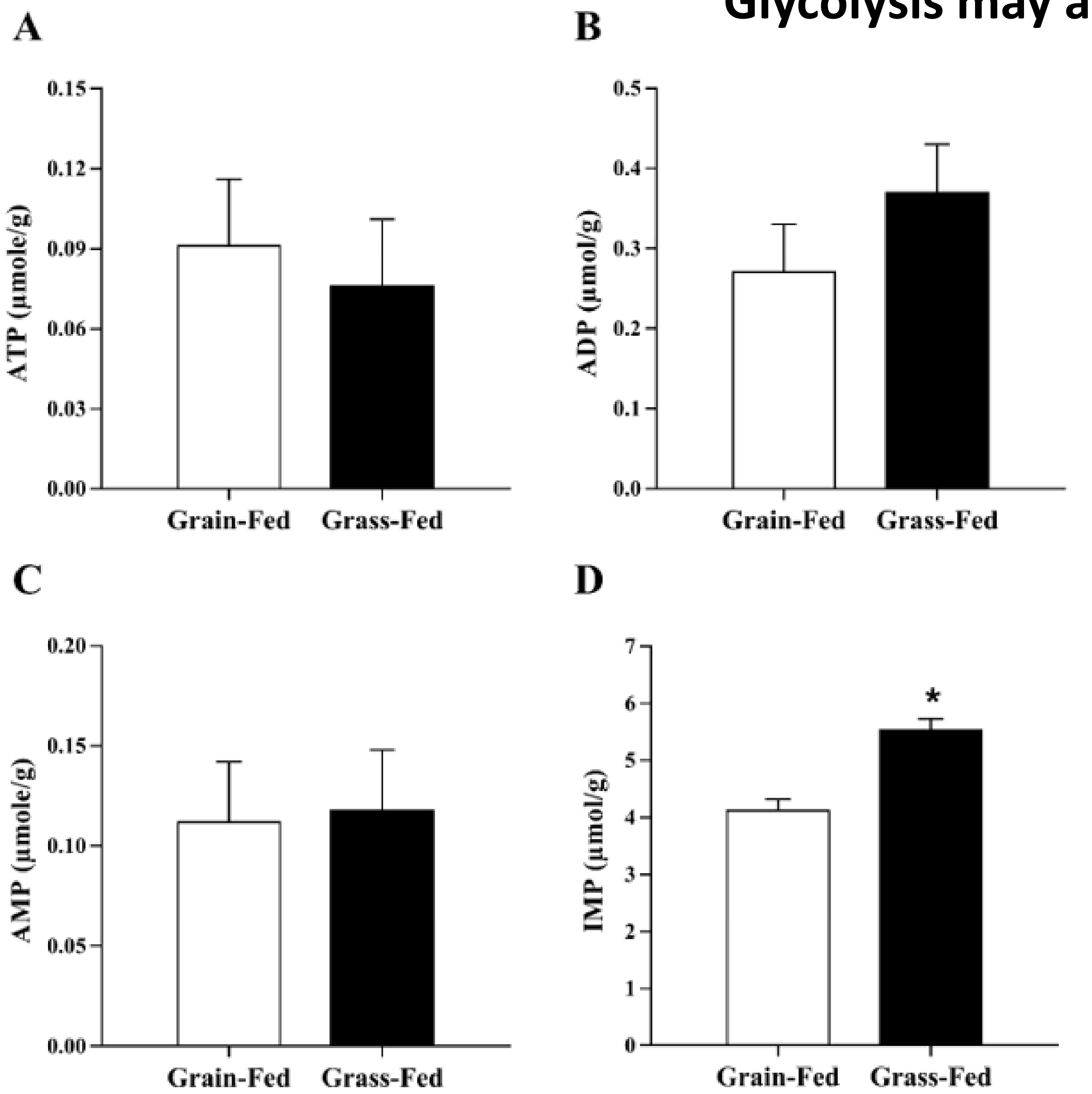

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Excess glycogen does not resolve high ultimate pH of oxidative muscle

Eric M. England [1], Sulaiman K. Matarneh, Emily M. Oliver, Ariel Apaoblaza, Tracy L. Scheffler [2], Hao Shi, David E. Gerrard *

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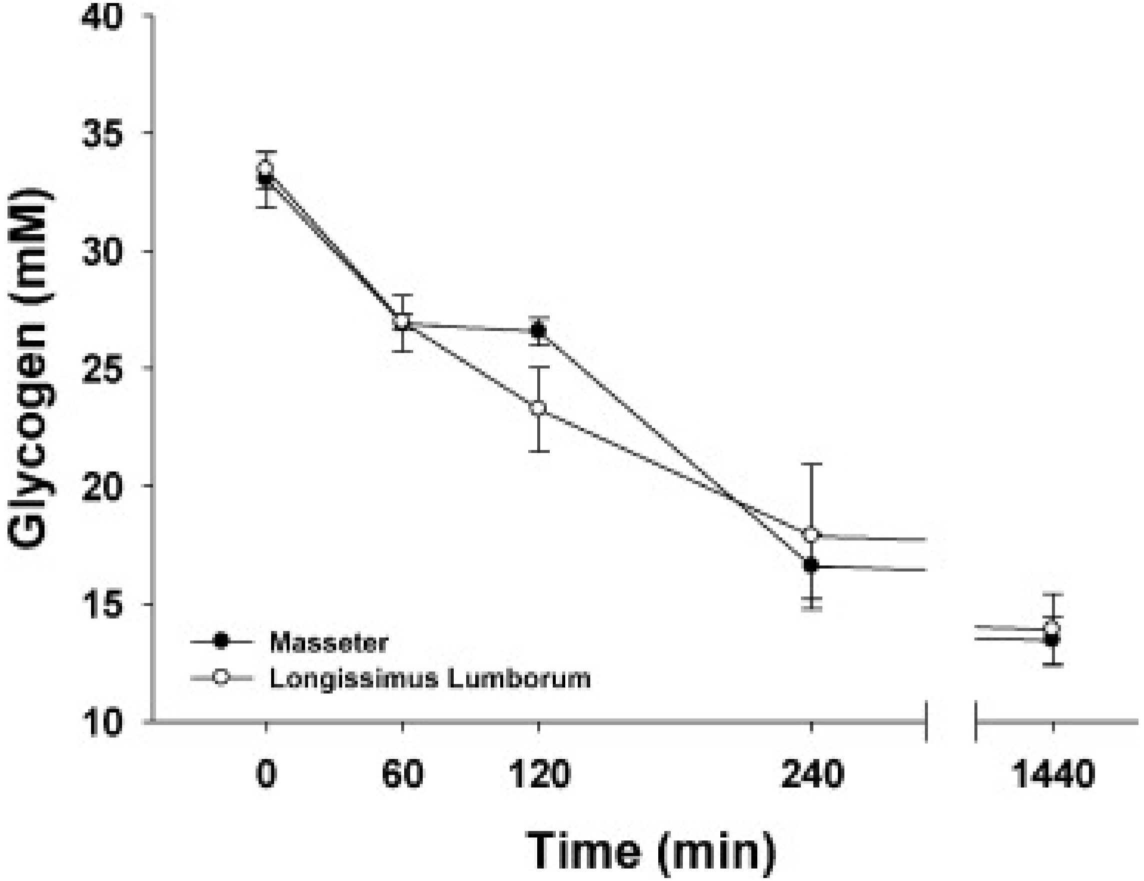
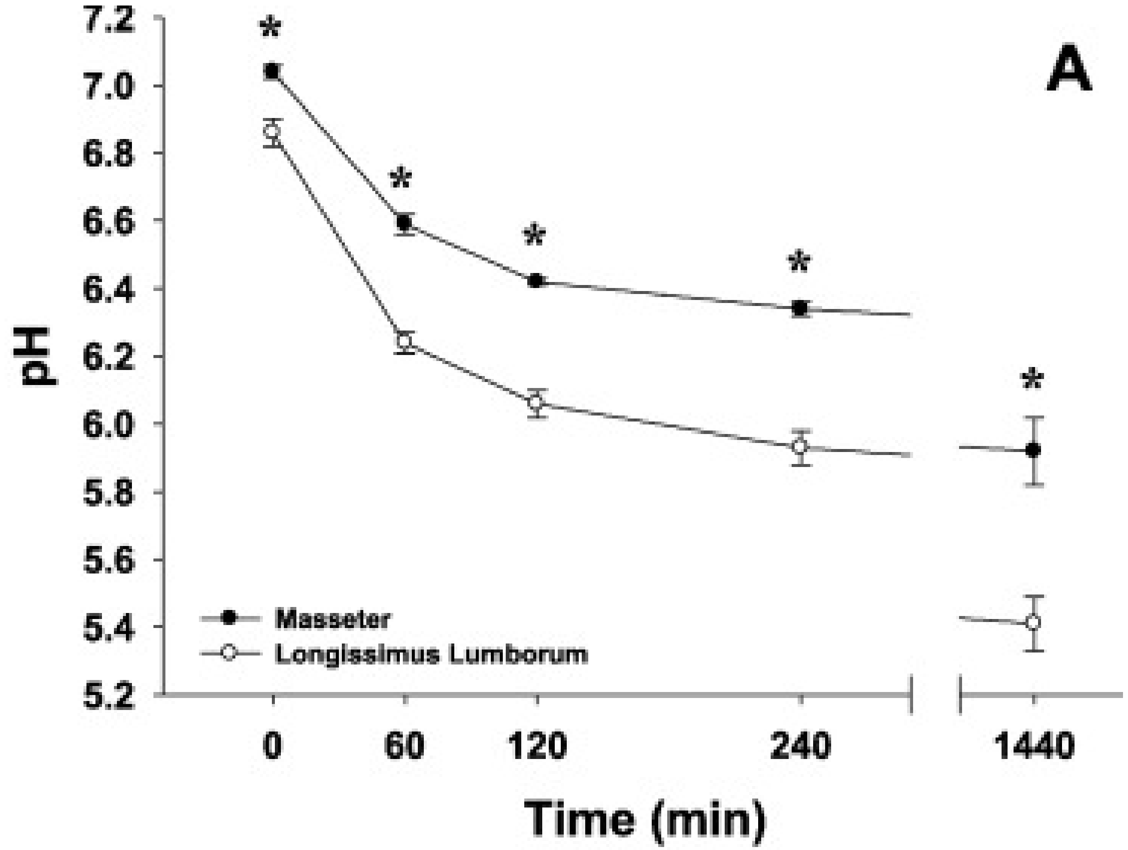
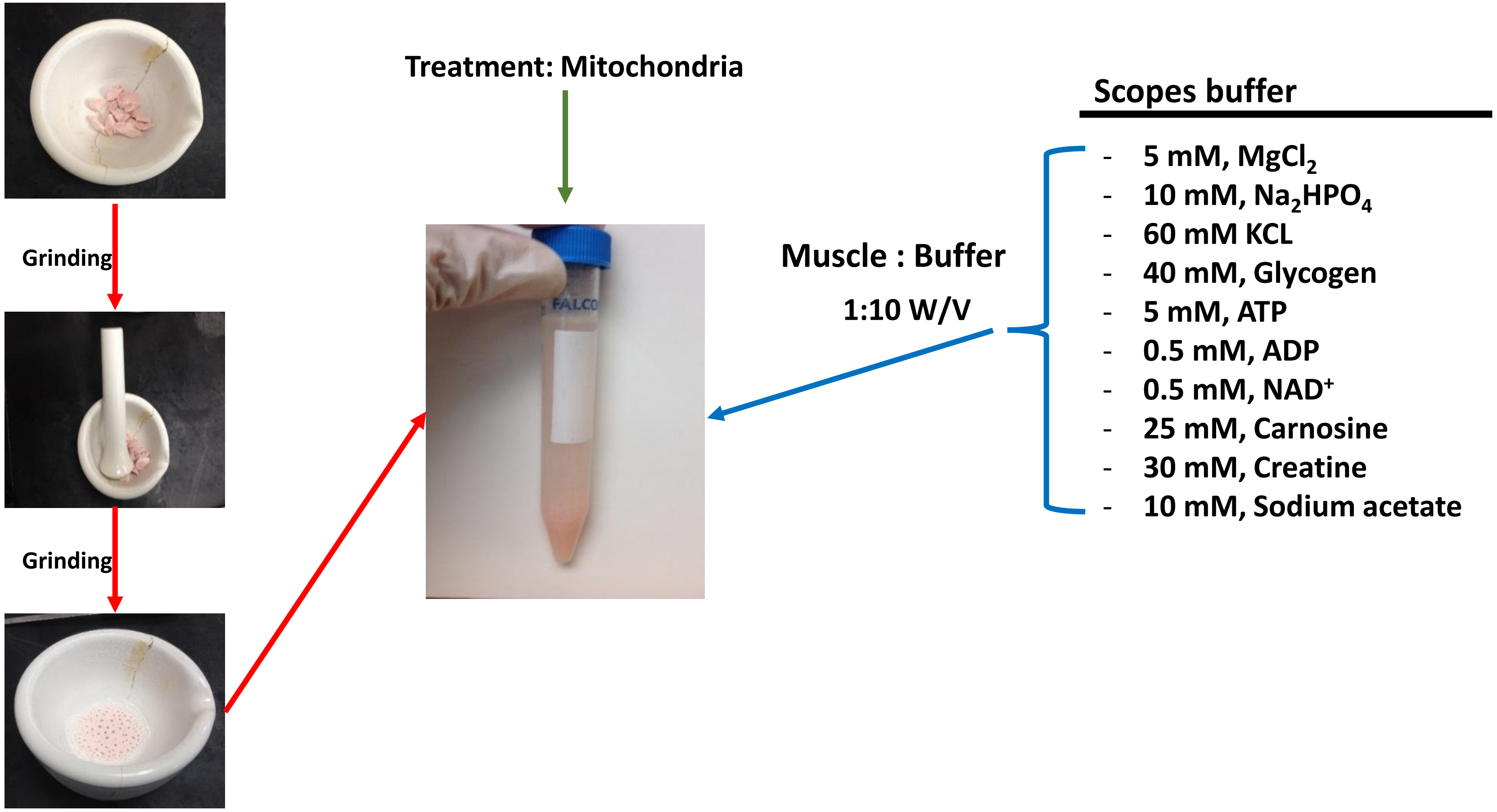


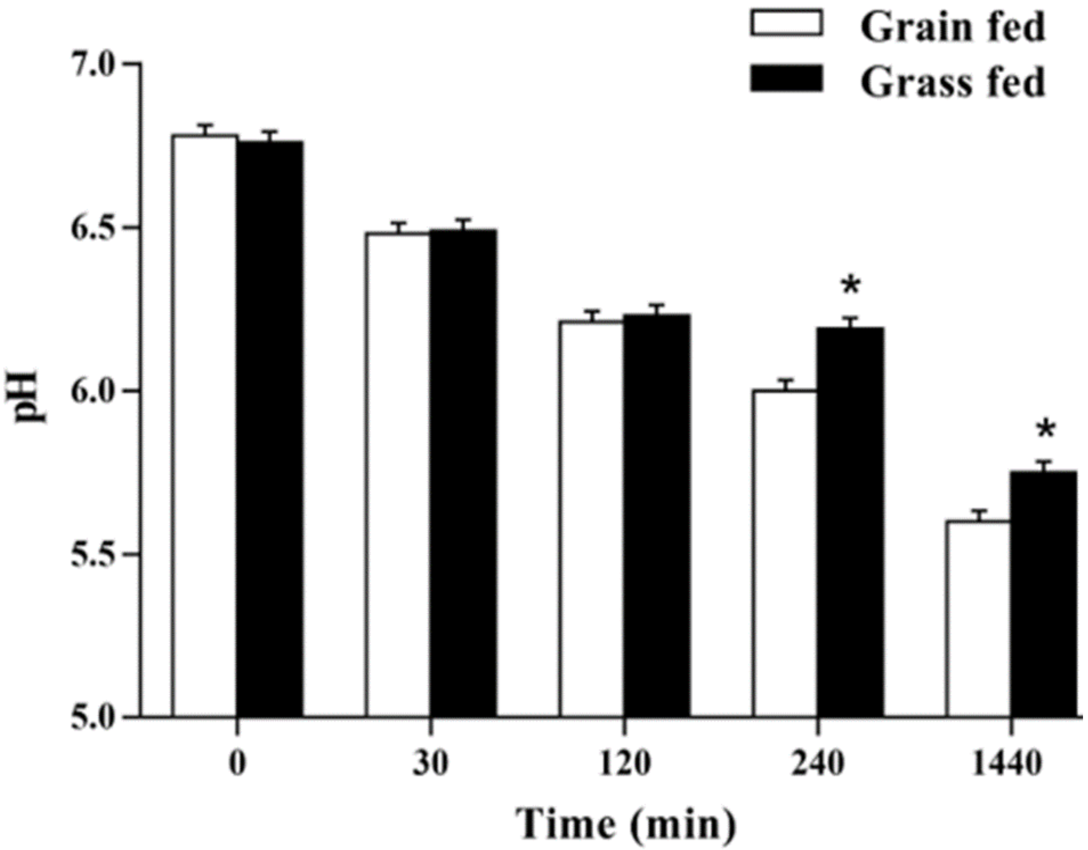


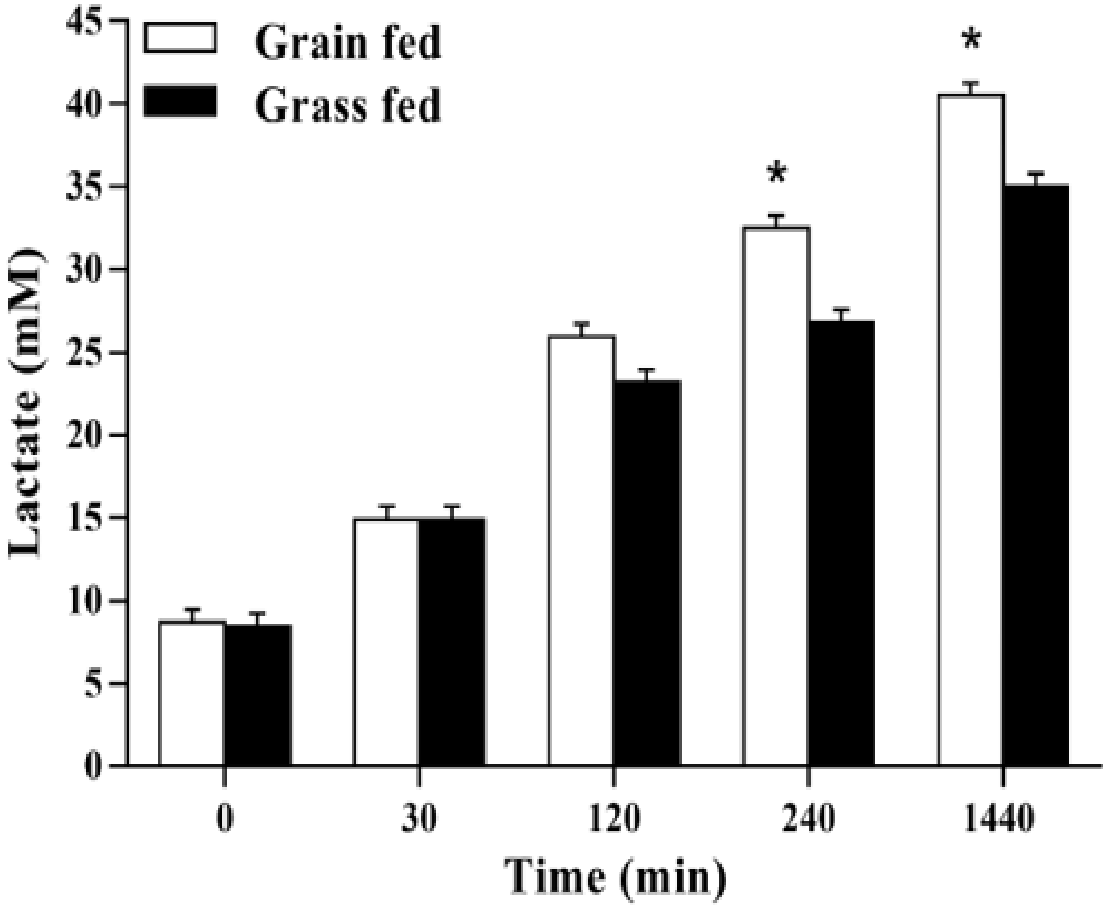
The *in vitro* system



In-Vitro Metabolism

Scopes System





Muscle from grass and grain-fed differ in their ability to metabolize carbohydrate

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Presence of oxygen and mitochondria in skeletal muscle early postmortem

Eric M. England[a,1], Sulaiman K. Matarneh[a,2], Rachel M. Mitacek[b], Anupam Abraham[b], Ranjith Ramanathan[b], Jordan C. Wicks[a], Hao Shi[a], Tracy L. Scheffler[c], Emily M. Oliver[a], Emma T. Helm[a], David E. Gerrard[a,*]

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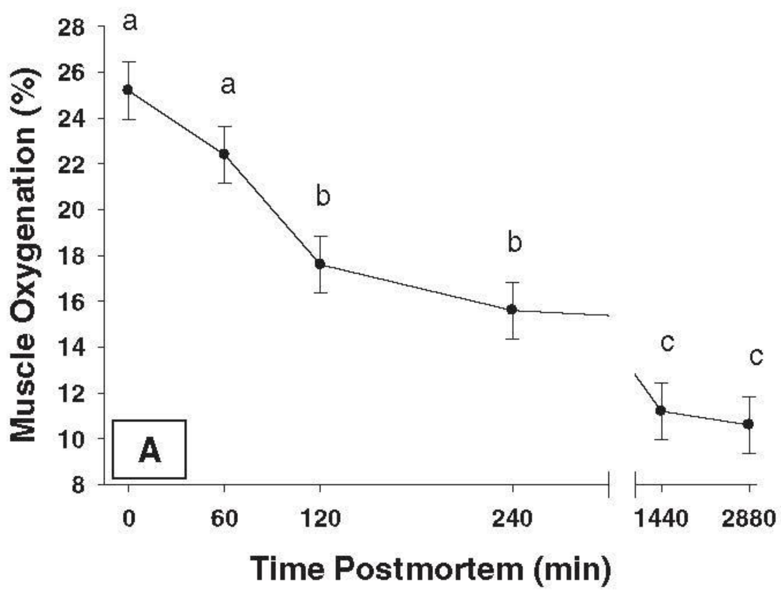
[b] Department of Animal Science, Oklahoma State University, Stillwater, OK 74078, United States
[c] Department of Animal Sciences, University of Florida, Gainesville, FL 32611, United States



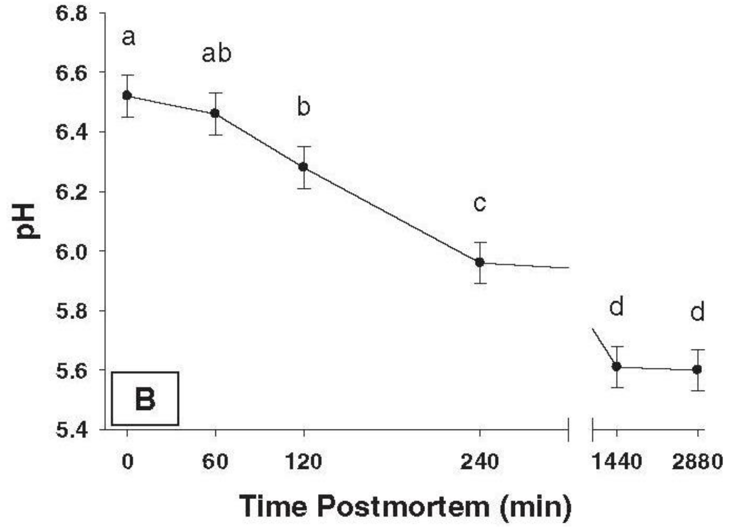


Fig. 3. (A) Mean postmortem muscle oxygenation (%) of the beef *longissimus thoracis et lumborum*. (B) Mean postmortem pH decline of the beef *longissimus thoracis et lumborum*. Data are presented as mean ± SEM. Means without a common superscript are significantly different ($P < 0.05$).

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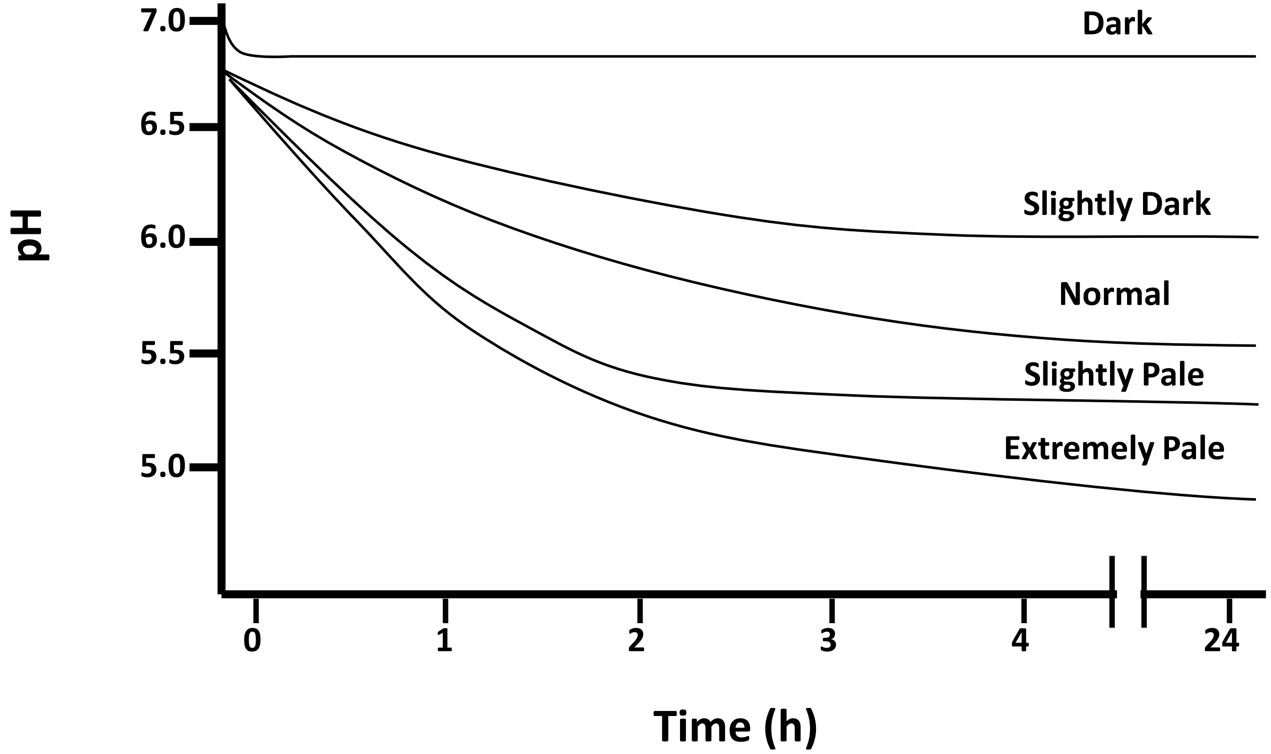
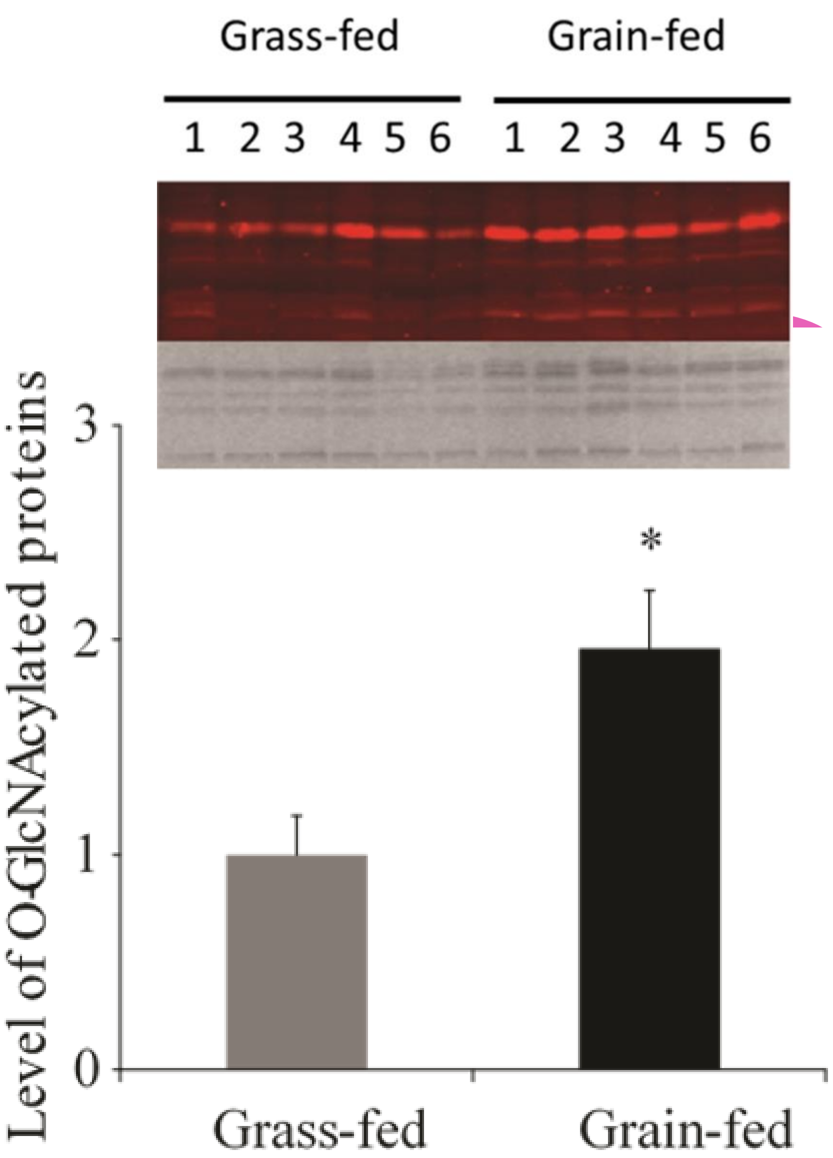
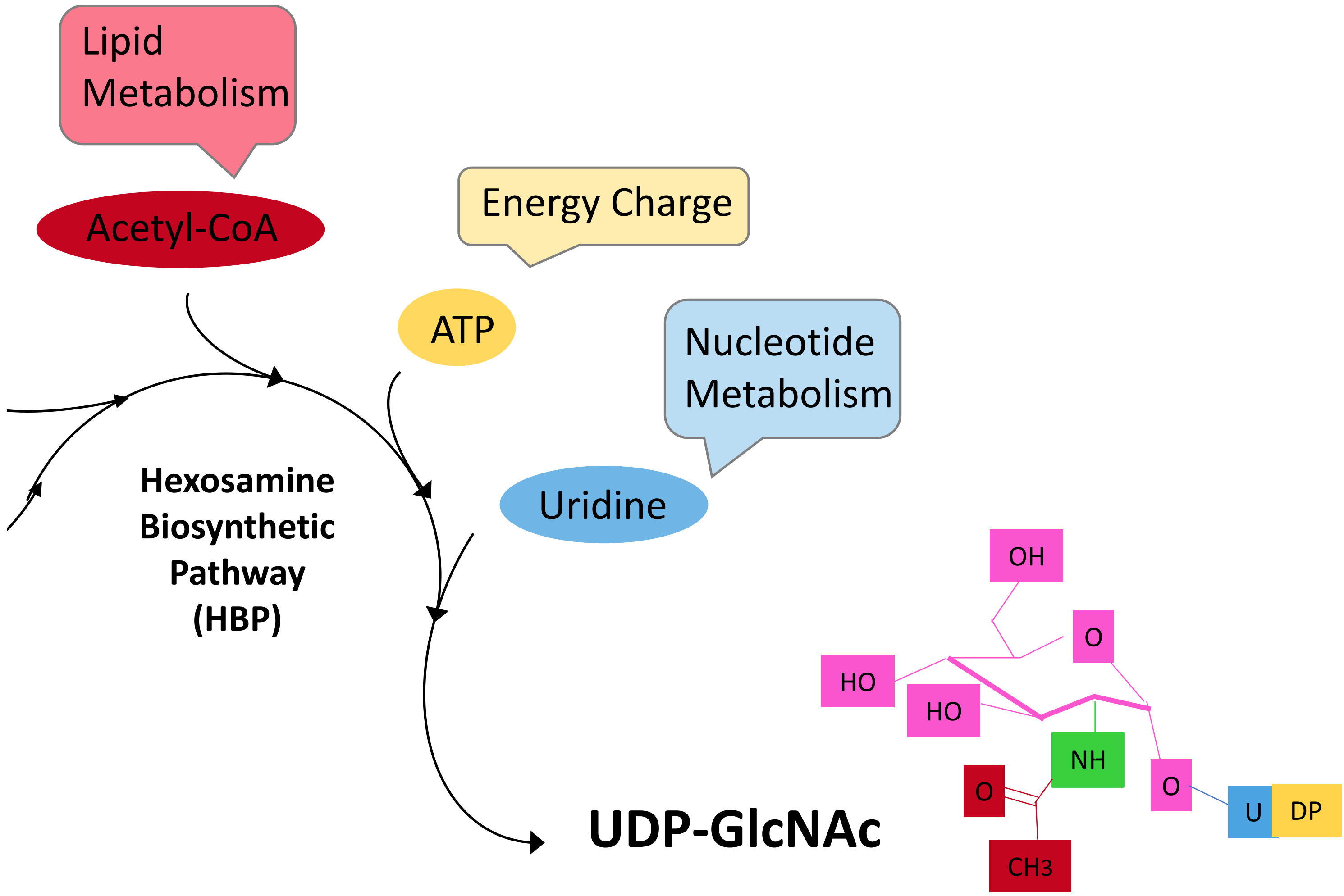

Dark
Slightly Dark
Normal
Slightly Pale
Extremely Pale
7.0
6.5
6.0
5.5
5.0
pH
0
1
2
3
4
24
Time (h)

Nutrient Signaling





Adapted from Hanover et al., (2012)

The color of normal (fresh or packaged) meat is bright cherry red and consumers tend to reject any deviation from this due to a perceived degradation in quality (Tarrant 1989; Sawyer and others 2009). (in Ponnampalam et al., 2017).

Conclusions

What we know:

Feeding regime impacts beef color

Muscle from ‘fed’ cattle have altered nutrient sensing

High forage-fed beef has more myoglobin

Lean from forage-fed beef is metabolically different

Dark beef has more oxidative metabolism

Forage and grain fed cattle modulate energy metabolism *in vitro* differently

Mitochondria modulate PM energy metabolism *in vitro*

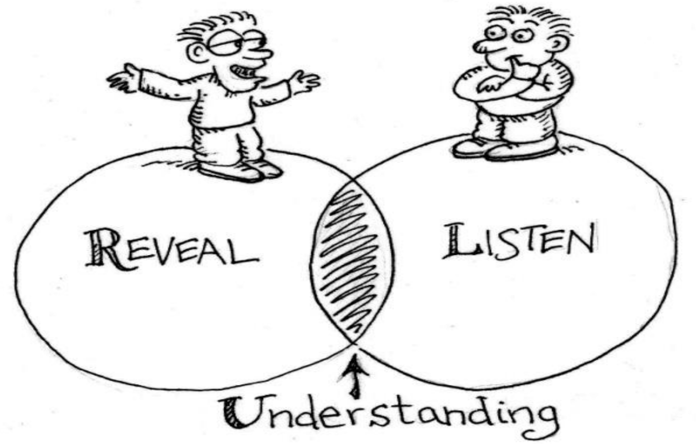
What we don’t know:

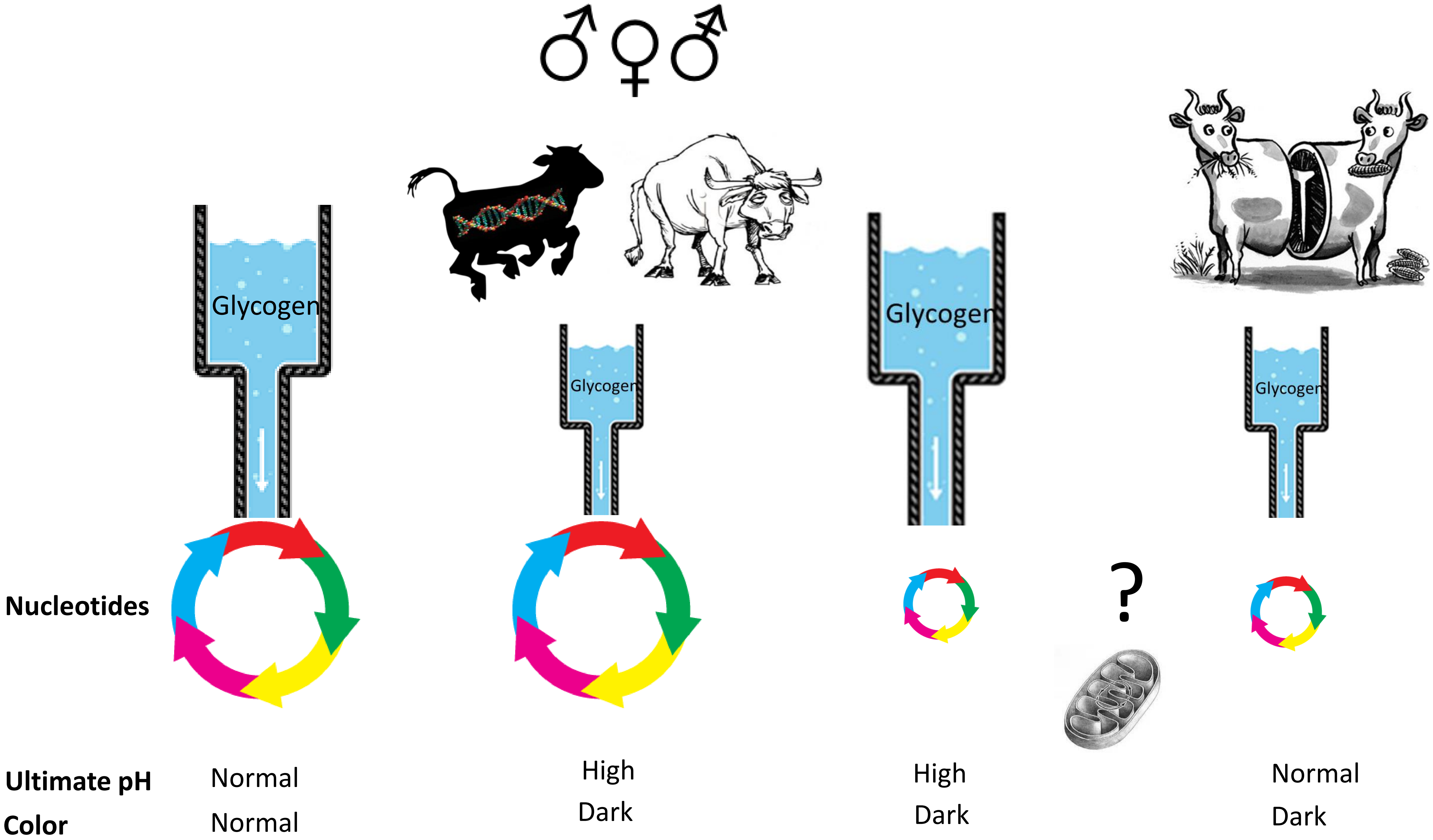
How mitochondria fully participate in PM muscle

What impact ‘moderate’ exercise has on beef color/quality

Feeding

- How much
- How long
- Reduced nutrient intake/weight loss





Glycogen
Glycogen
Glycogen
Glycogen
Nucleotides
?
Ultimate pH
Color
Normal
Normal
High
Dark
High
Dark
Normal
Dark

- Susan Duckett, Clemson
- Saulo da Luz e Silva, USP
- Luzardo, Brito, del Campo, Montossi, INIA
- Aalhus, AAFC/AAC
- Ariel Apaoblaza

USDA
NIFA