SASDT congress 2002

MILK:
the well-known(?) food

Prof G Osthoff

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA

UFS·UV
NATURAL AND
AGRICULTURAL SCIENCES
NATUUR- EN
LANDBOUWETENSKAPPE

CONTENTS

Background about milk

General composition

Saccharides

Lipids/Fats

Proteins

(*Lessons for Technology & Nutrition*)

Future

Milk comes from the supermarket

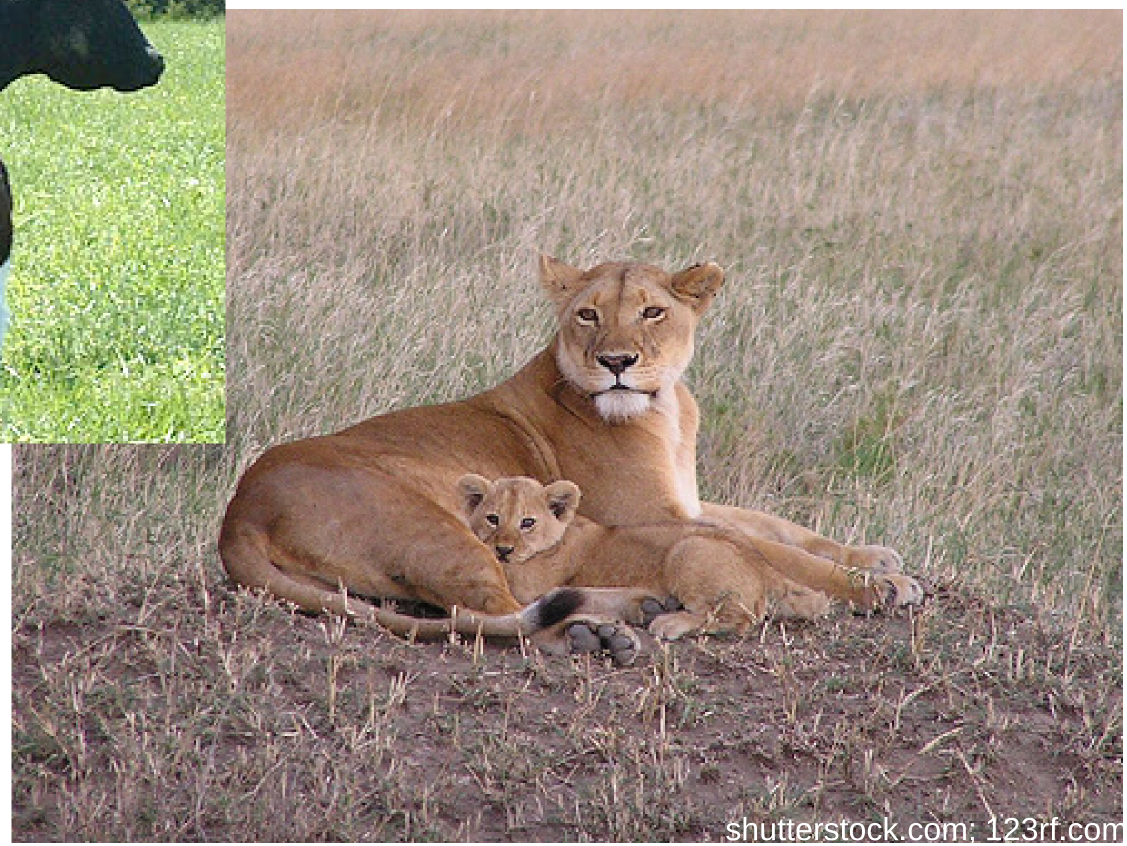
Wikipedia

Milk comes from a cow?

randomactsoflindz.blogspot.com

What the consumer of milk and dairy products has forgotten, is that milk is the first food to be utilized by ***young*** mammals……

…. and that milk is custom-designed for each species.



Mankind is an opportunist and has found ways of easy access to food by the practice of agriculture.

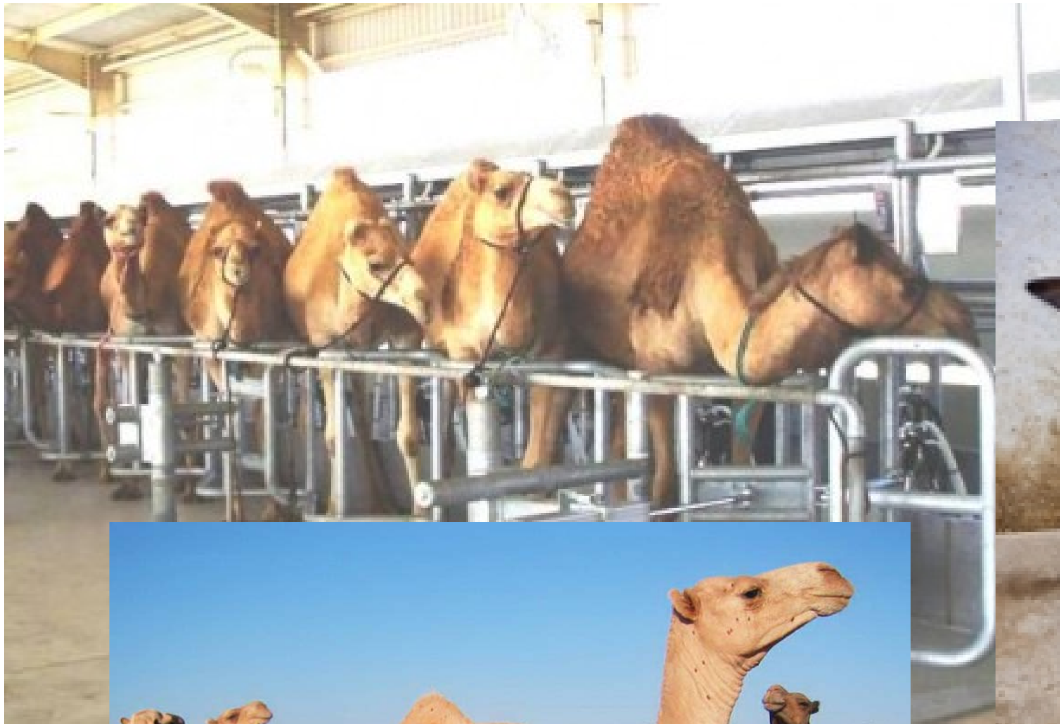
Plants and animals are employed (exploited?)

corbisimages.com; flickr.com

The cow is the best milk producer. Other animals are also employed.

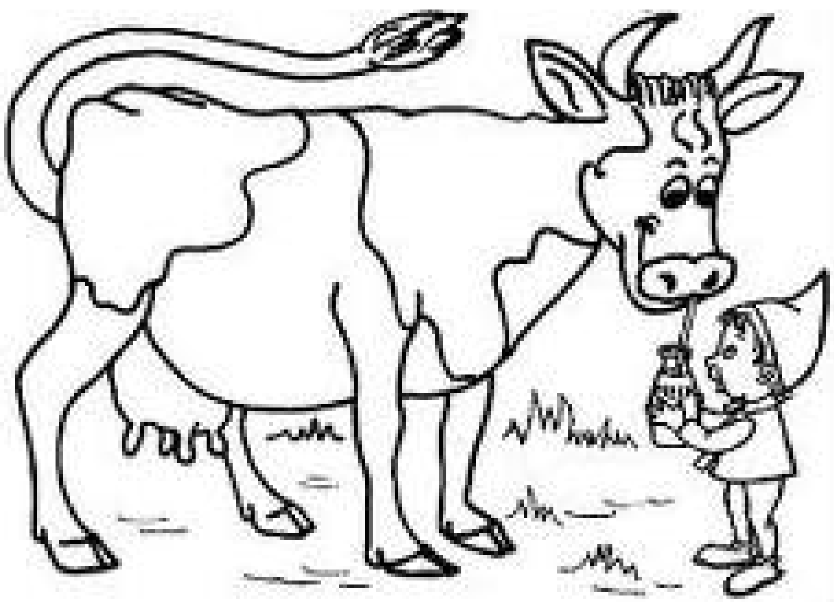
nsf.gov ; flickr.com; jozan.net

Cattle have not adapted to the most extreme conditions.



en.kllproject.lv ; gulfnews.com; healthbanquet.com

The consumption of the milk as grownup is not natural. Neither is the consumption of milk across species.



clipartof.com;corbisimages.com

Malnutrition or diseases: allergy to milk and lactose intolerance

kidsfoodallergyclinic.com ; qwickstep.com

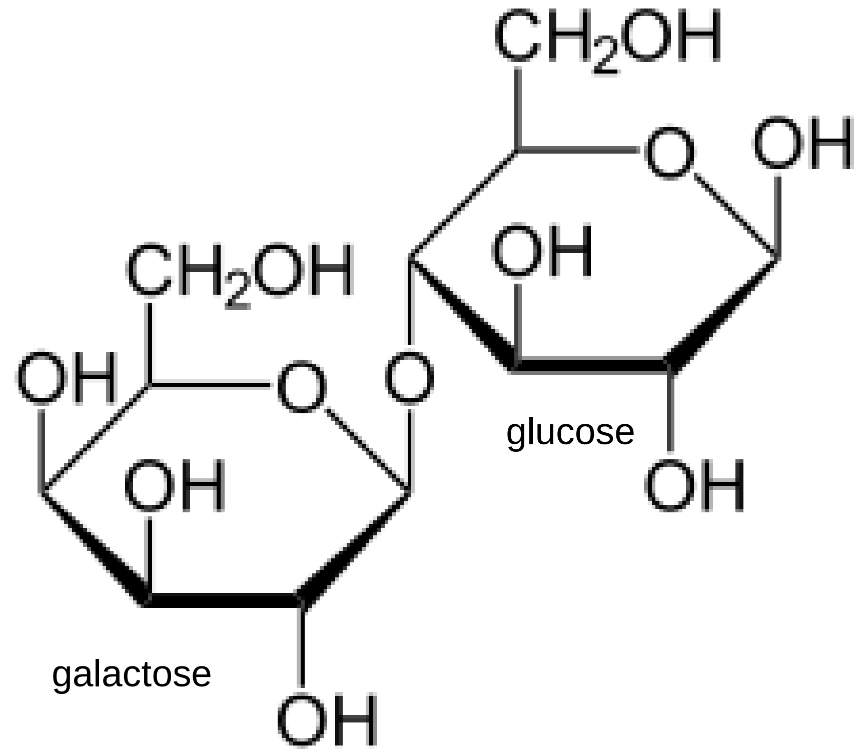
Allergies are the result of an immune response to the foreign proteins in the milk.

Switch from cow's milk to goat's milk.

nasubionna.deviantart.com

Lactose intolerance:
inability of adult humans to digest lactose (milk sugar).
This is natural;
grownups lose the ability to digest lactose.
Symptoms:
stomach cramps and

diarrhoea.

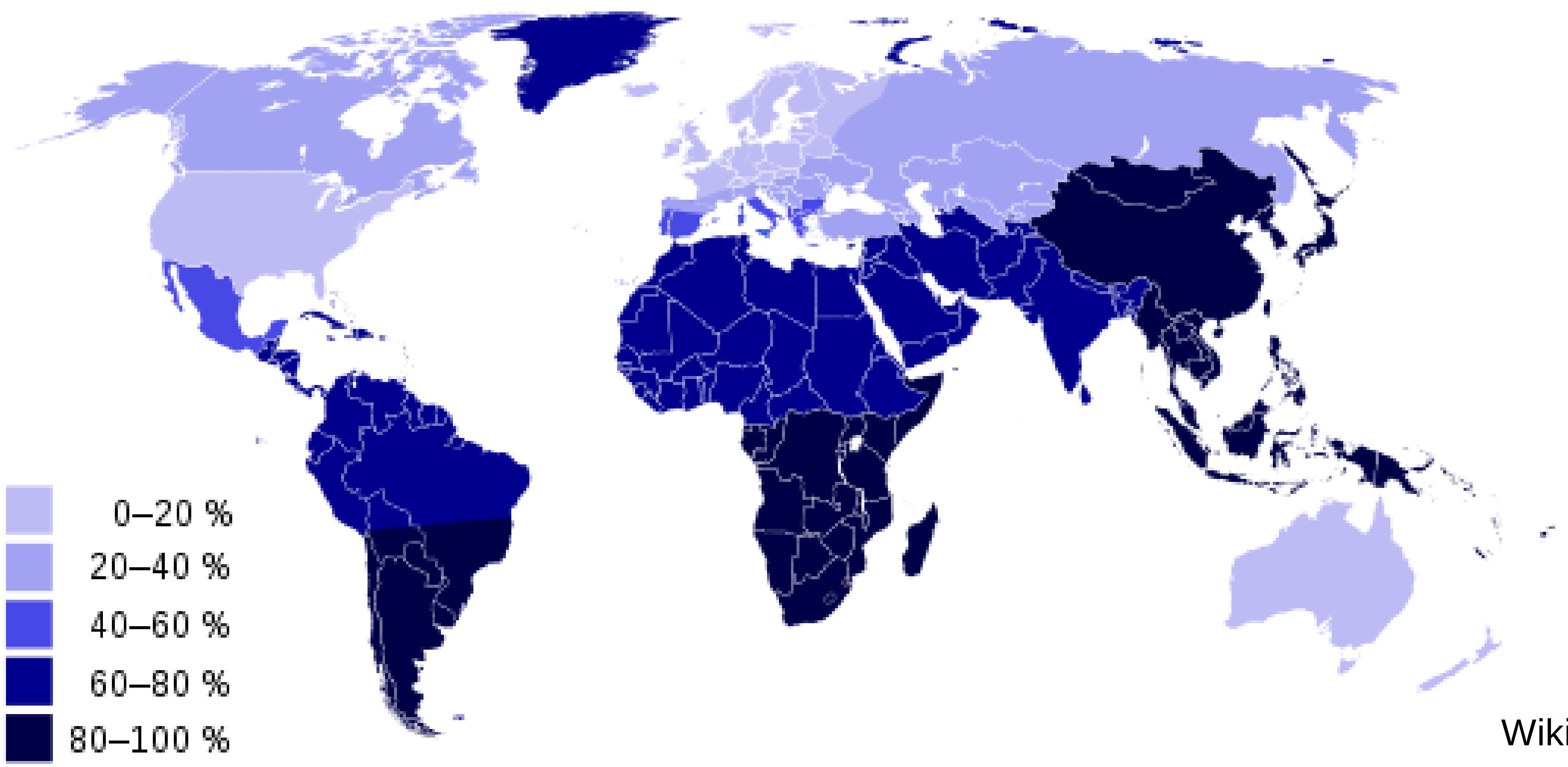


Lactose intolerance mainly found in the warmer climates of the world.

Milk not stored fresh - *fermented*.

This human population never adapted to digesting lactose in adulthood.

An early passive development of dairy technology.



Wikipedia

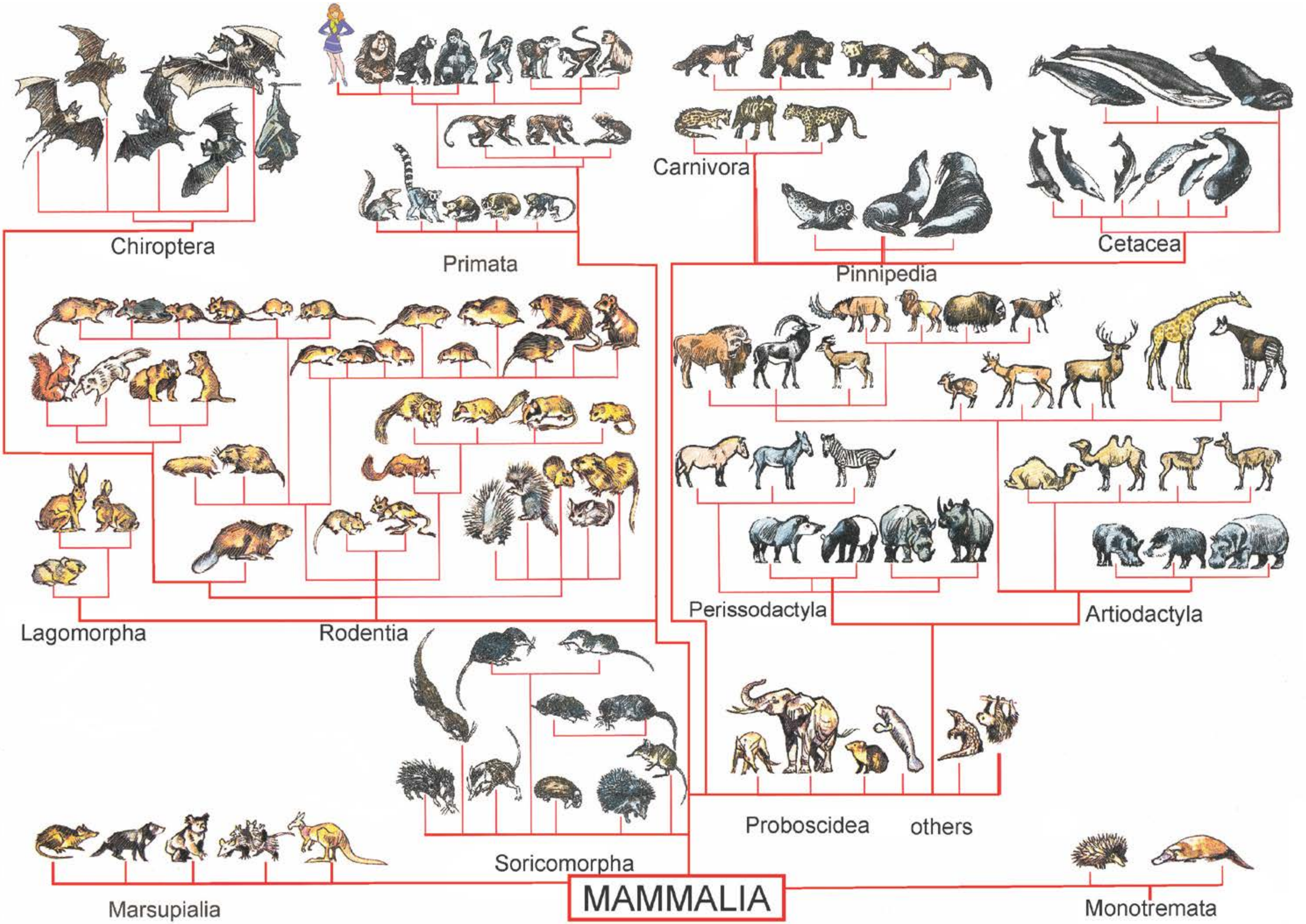
Lactose in milk has spurred dairy technology: Lactose fermentation by micro-organisms.

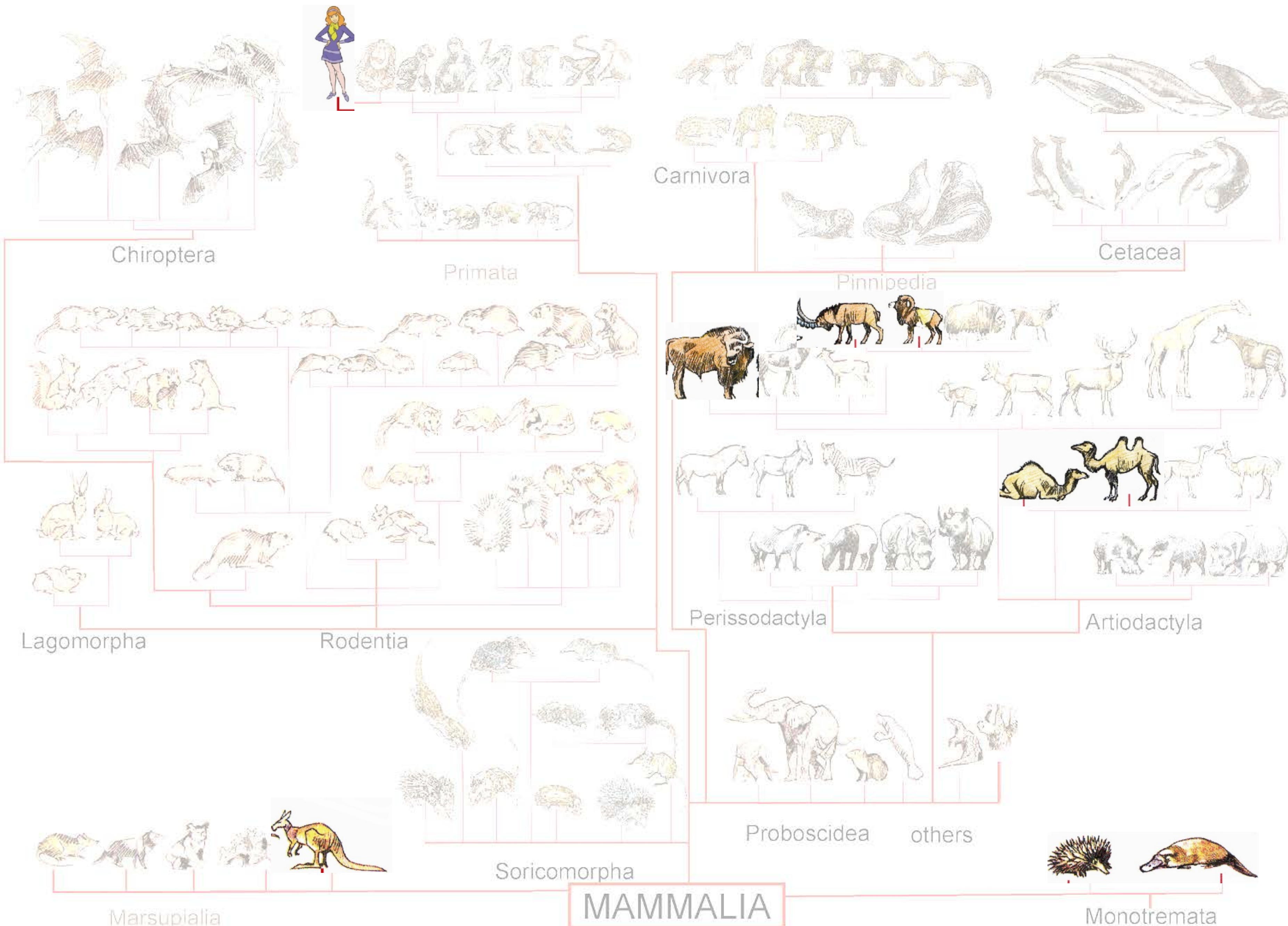
Cheese

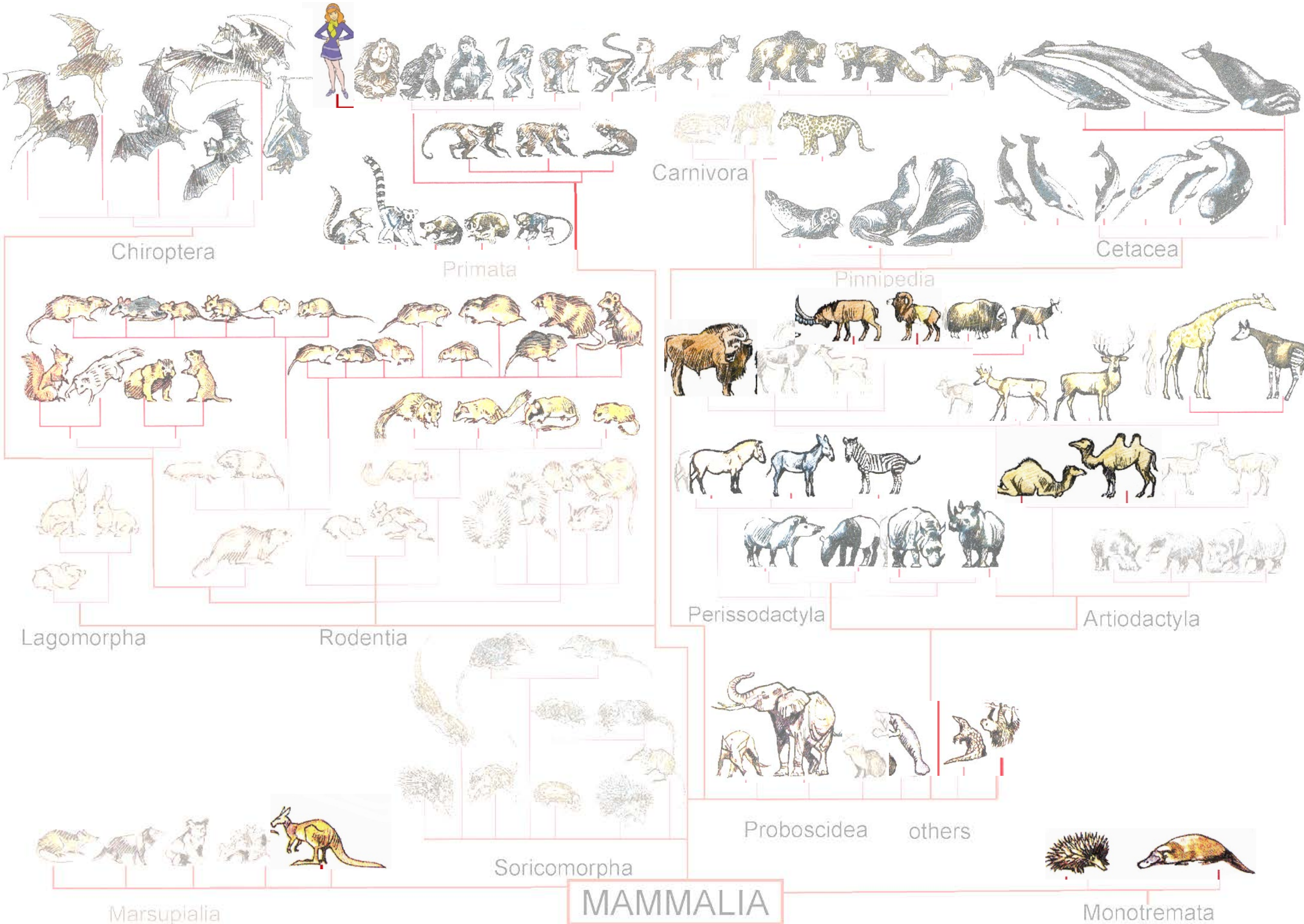
Lactose free milk

Arla.com

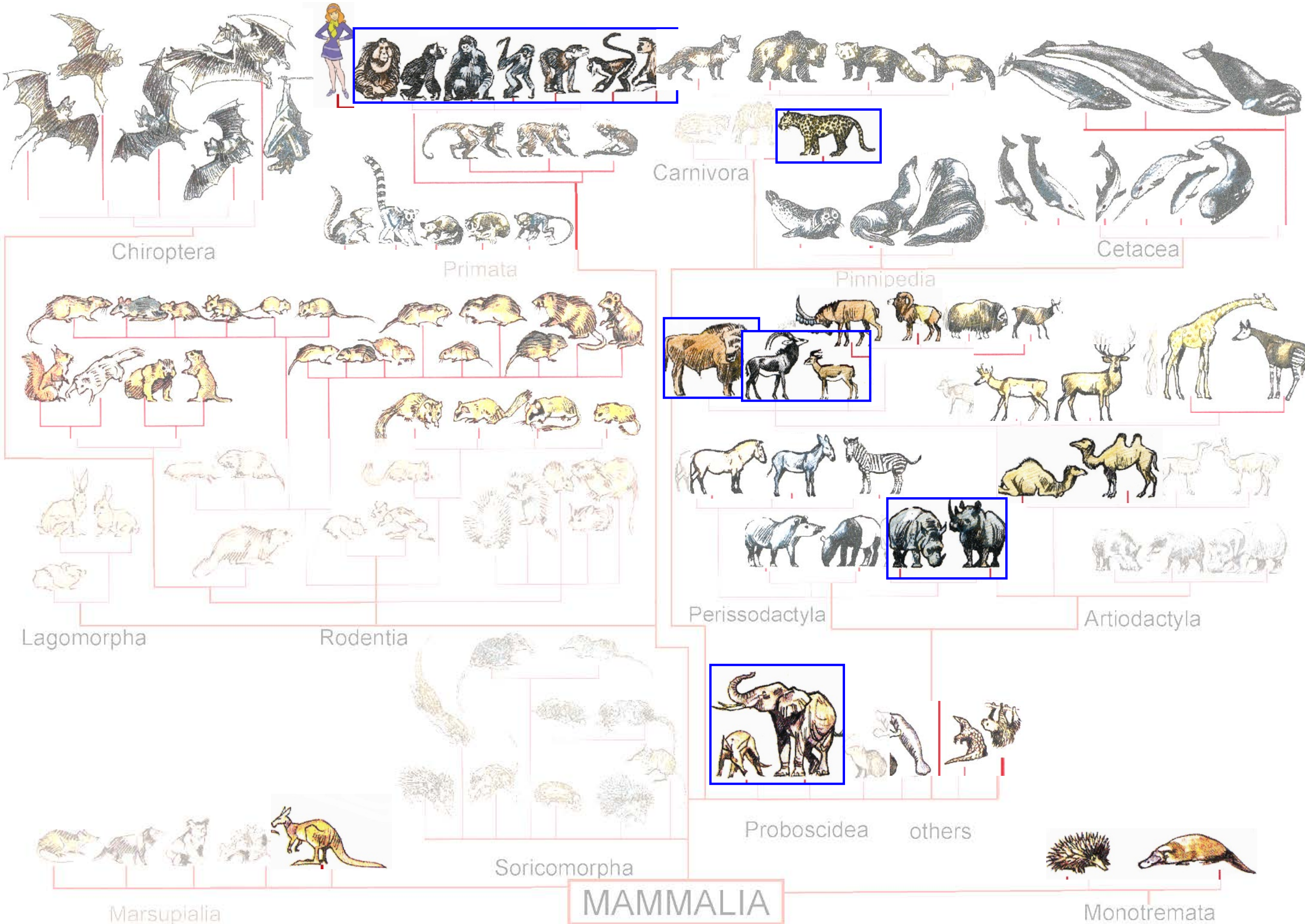

Humankind has also employed other animals to produce milk with derived dairy products.
Milks and products from different species differ in keeping properties, taste, nutritional properties, their effects on health.
Knowledge of human milk and that of the few domesticated species does not provide a complete explanation of the properties of milk as food.
blog.thegreenplate.org


Chiroptera
Primata
Carnivora
Pinnipedia
Cetacea
Lagomorpha
Rodentia
Perissodactyla
Artiodactyla
Proboscidea
others
Soricomorpha
Marsupialia
MAMMALIA
Monotremata


Chiroptera
Primata
Carnivora
Pinnipedia
Cetacea
Lagomorpha
Rodentia
Perissodactyla
Artiodactyla
Soricomorpha
Proboscidea
others
Marsupialia
MAMMALIA
Monotremata



Chiroptera
Primata
Carnivora
Pinnipedia
Cetacea
Lagomorpha
Rodentia
Perissodactyla
Artiodactyla
Proboscidea
others
Soricomorpha
Marsupialia
MAMMALIA
Monotremata


Chiroptera
Primata
Carnivora
Pinnipedia
Cetacea
Lagomorpha
Rodentia
Perissodactyla
Artiodactyla
Proboscidea
others
Soricomorpha
Marsupialia
MAMMALIA
Monotremata

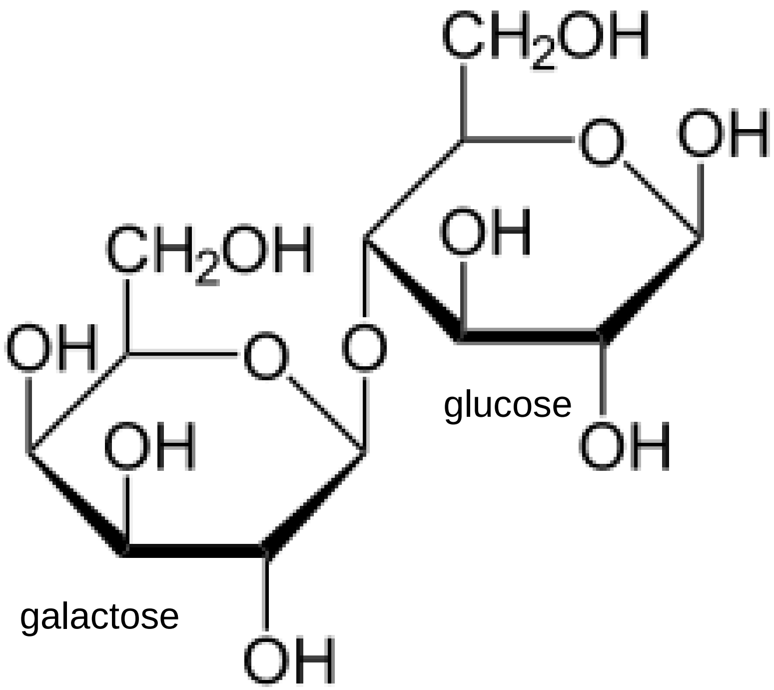
Each species provides nutrients and bio-reactive components in the correct amount and form; the result of adaptation to environmental opportunities and physiological constraints.

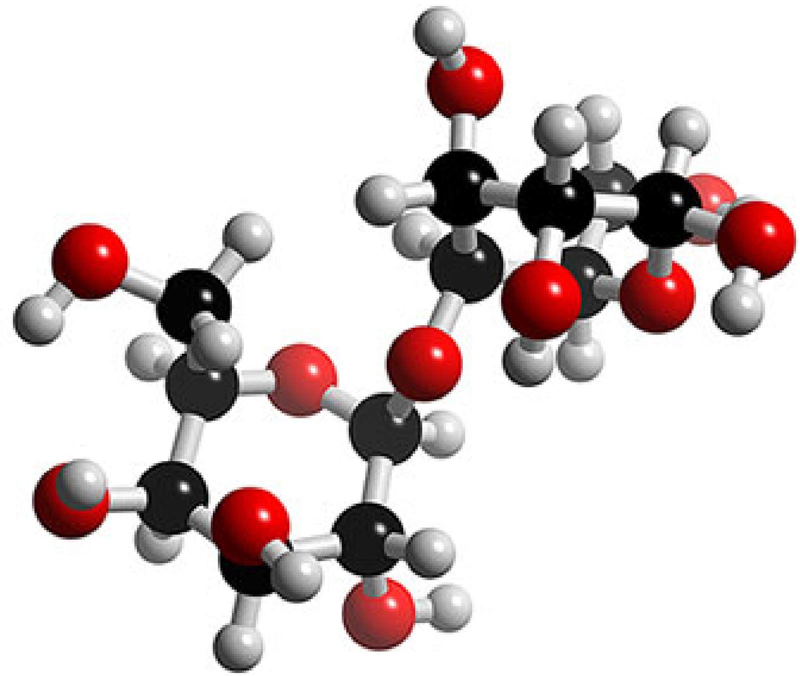
	Primata	Bovidae		Felidae		Proboscidae	Perissodactyla
Nutrients (%)	Human	Cow	Springbok	Cheetah	Serval	African Elephant	White Rhino
Fat	4	3.9	14.5	6.5	15.36	8.7	0.7
Protein	0.8	3.2	7.4	9.9	14.3	5.2	1.6
Casein	0.2	2.6	6.0	3.4	11.8	3.2	0.3
Whey	0.6	0.6	1.4	6.5	4.1	2.0	1.3
NPN	2.2	0.05	0.07	0.1	0.5	0.07	0.03
Saccharide	8.5	4.6	4.3	4.0	0.7	4.1	7.6
Lactose	7.3	4.6	4.3	4.0	0.7	1.5	7.5
Oligosacch.	1.2	0.1	0.3	0.02	0	2.7	0.05

(Osthoff et al. 2005;2006; 2007, 2008; 2009)

SACCHARIDES

Lactose





Saccharide content of mammalian milk

Species		Lactose (%)	Oligo-saccharides (%)
Monotremes (No α-Lactalbumin)		≈ 0	3.7
Marsupials (No α-Lactalbumin)		1-2	4.6-12.0
	Seal (No α-Lactalbumin)	0	0
	Sea lions(Low α-Lactalbumin)	0.5	0.3
Eutherian (High α-Lactalbumin)	Cow	4.0	0.1
	Sable antelope	4.1	0.4
	Human	7.3	1.2
	Gorilla	6.2	0.7
	African elephant	0.7-5.3	1.5-2.7

(Iverson & Oftedal, 1995; Messer & Urashima 2002; Osthoff et al, 2007; 2008; 2009)

Selection of oligosaccharides in mammalian milk

Lactose Gal β(1-4) Glc

2'-Fucosyllactose

Fuc α(1-2) Gal β(1-4) Glc

DF-para-LNnHexaose

Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) Glc

| **|**

Fuc α(1-3) **Fuc α(1-3)**

DF-para-LNnNonaose

Gal α(1-3) Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) Glc

| **|**

Fuc α(1-3) **Fuc α(1-3)**

(Osthoff et al. 2008)

DF-LNH

Gal β(1-4) GlcNAc β(1-6) Gal β(1-4) Glc

| **|**

Fuc α(1-3)

Gal β(1-4) GlcNAc β(1-3)

|

Fuc α(1-3)

250+ structures known
12 structural groups
Different chain types

(Urashima et al. 2001)

Selection of oligosaccharides in mammalian milk

Note the Type II bond Gal β(1-4) GlcNAc

Lactose Gal β(1-4) Glc

2'-Fucosyllactose

Fuc α(1-2) Gal β(1-4) Glc

DF-para-LNnHexaose

```
Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) Glc
              |                    |
   Fuc α(1-3)          Fuc α(1-3)
```

DF-para-LNnNonaose (Only in elephant) (Osthoff et al. 2008)

```
Gal α(1-3) Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) GlcNAc β(1-3) Gal β(1-4) Glc
                           |                              |
              Fuc α(1-3)                     Fuc α(1-3)
```

DF-LNH

```
Gal β(1-4) GlcNAc β(1-6) Gal β(1-4) Glc
                |          |
     Fuc α(1-3)            |
                           |
     Gal β(1-4) GlcNAc β(1-3)
                           |
                  Fuc α(1-3)
```

(Urashima et al. 2001)

Selection of oligosaccharides in human milk

Note the Type II bond Gal β(1-4) GlcNAc (in all species)

Note the Type I bond Gal β(1-3) GlcNAc (predominant in primates)

Lactose Gal β(1-4) Glc

Lacto-N-tetraose

Gal β(1-3) GlcNAc β(1-3) Gal β(1-4) Glc

Lacto-N-hexaose

```
Gal β(1-4) GlcNAc β(1-6) Gal β(1-4) Glc
                         |
      Gal β(1-3) GlcNAc β(1-3)
```

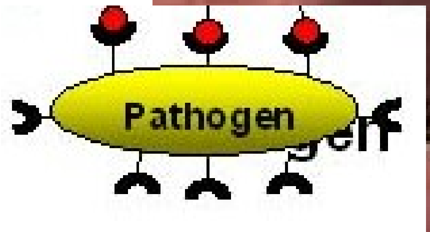
Lacto-N-Decaose

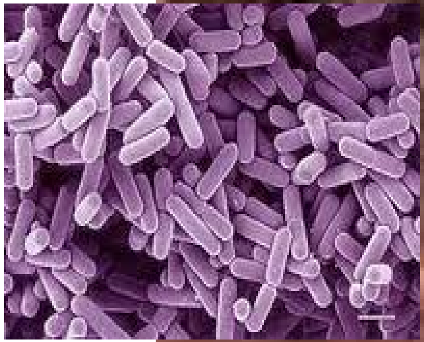
```
   Gal β(1-4) GlcNAc β(1-6)
                      |
                      Gal β(1-4) GlcNAc β(1-6) Gal β(1-4) Glc
                      |                        |
    Gal β(1-3) GlcNAc β(1-3)                   |
                                               |
                         Gal β(1-3) GlcNAc β(1-3)
```

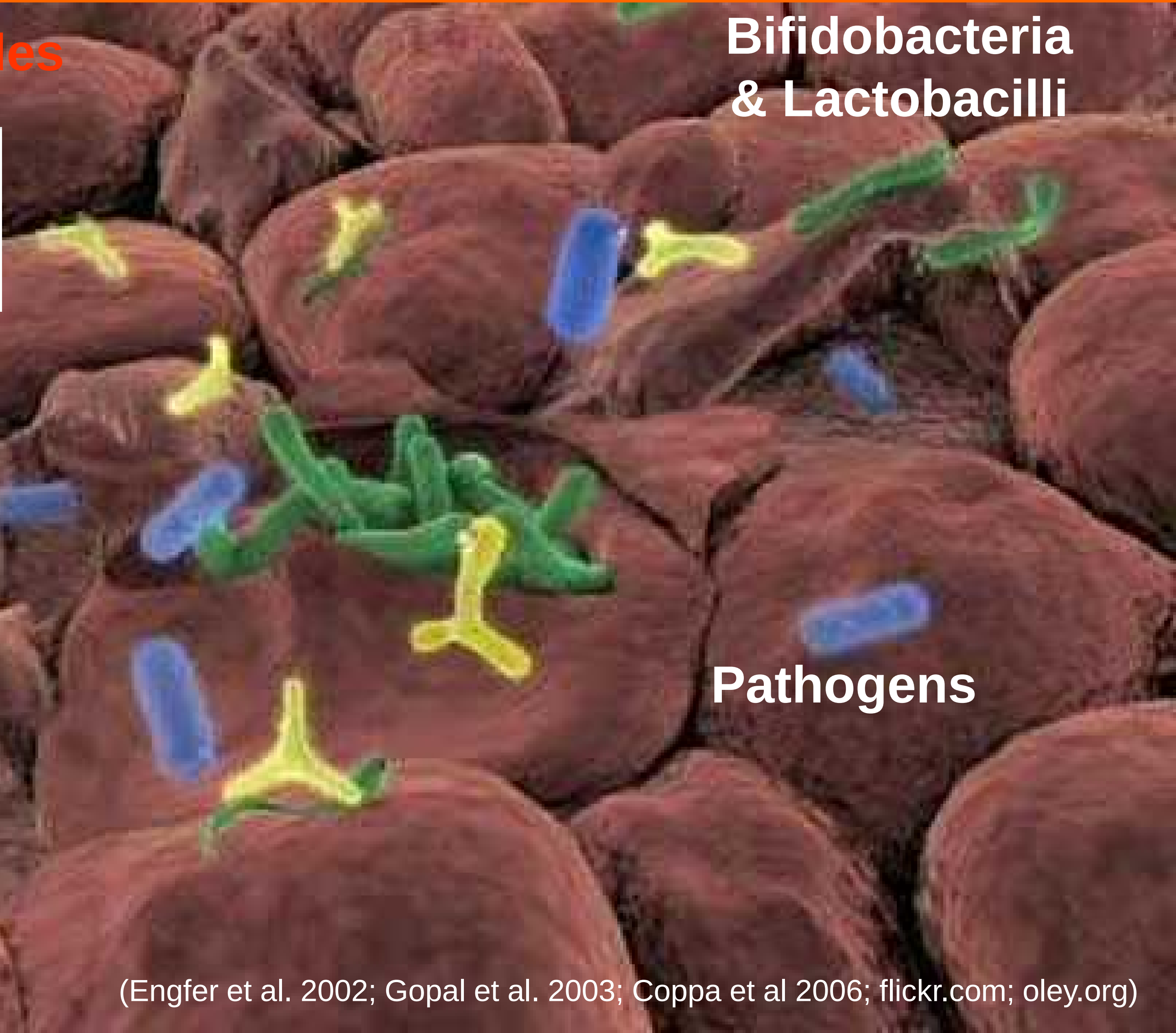
(Urashima et al. 2007)

Oligosaccharides and intestinal micro-organisms

Oligosaccharides







(Engfer et al. 2002; Gopal et al. 2003; Coppa et al 2006; flickr.com; oley.org)

Predominant anaerobic microorganisms in the human colon

Microbial group	Range in log counts (g dry wt^{-1})
Bacteroides	9.2-13.5
Eubacteria	5.0-13.3
Bifidobacteria	4.9-13.4
Clostridia	3.3-13.1
Lactobacilli	3.6-12.5
Ruminococci	4.6-12.8
Peptostreptococci	3.8-12.6
Peptococci	5.1-12.9
Streptococci	7.0-12.3
Methanobrevibacter	7.0-10.3
Desulfovibrios	5.2-10.9
Lactococci, Enterococci,	*Pediococci, Leuconostoc*

(Musatto & Mancilha, 2007)

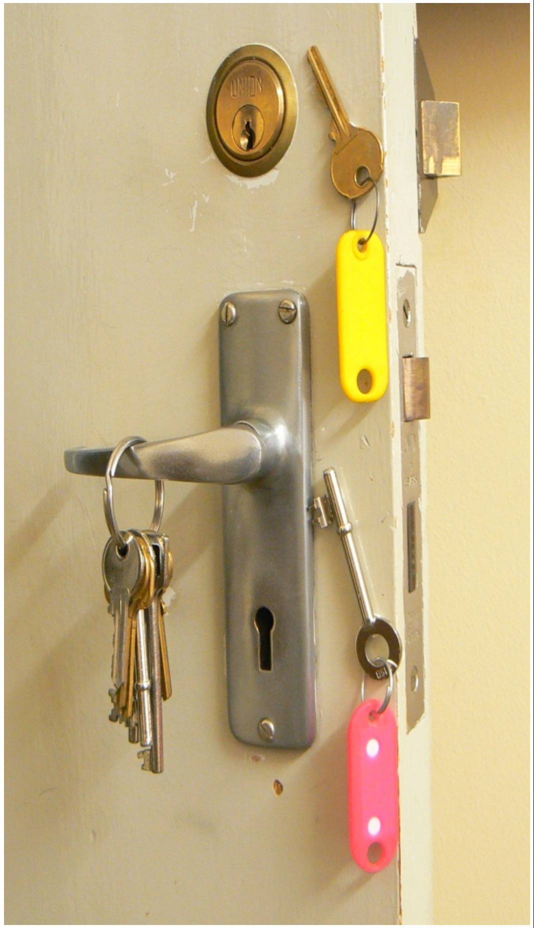
Saccharide bonds of human and plant oligosaccharides

Human oligosaccharides	Saccharide bond	
Fucosyllactose	α1-2, β1-4, α1-3	
Lacto-N-tetraose	β1-4, β1-3	
Sialyllactose	β1-4, α2-3, α2-6	
Sialyllacyo-N-tetraose	β1-4, α2-3, α2-6, β1-3	
Plant oligosaccharides		
Fructo-oligosaccharides	β1-2	
Galacto-oligosaccharides	β1-4, α1-6	
Transgalacto- oligosaccharides	β1-4, β1-6	
Soybean oligosaccharides	α1-2, α1-6	

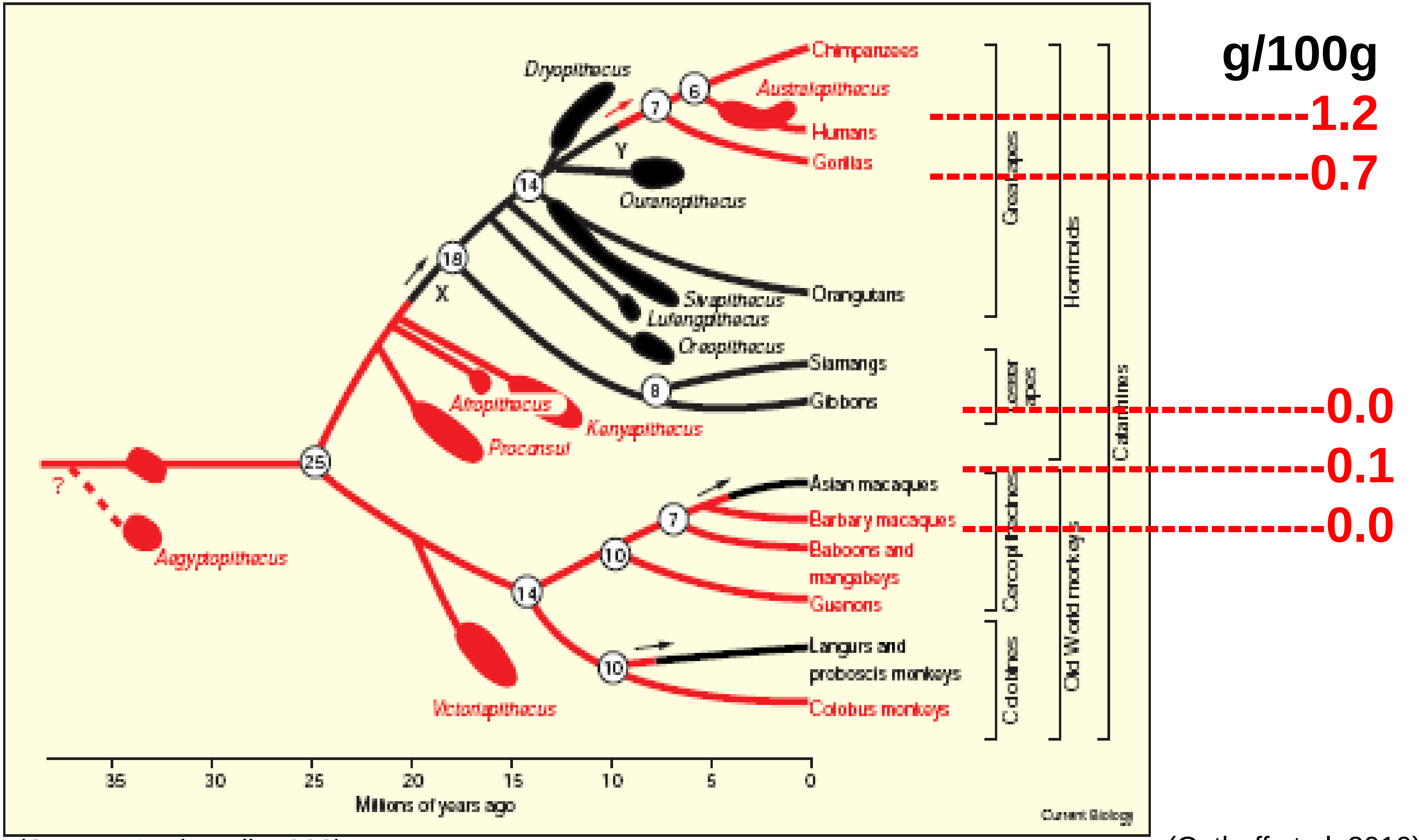
(Crittenden et al. 1996; Urashima et al. 2001;2007)

Saccharide bonds of human and plant oligosaccharides

Human oligosaccharides	**Saccharide bond**
Fucosyllactose	**α1-2, β1-4, α1-3**
Lacto-N-tetraose	**β1-4, β1-3**
Sialyllactose	**β1-4, α2-3, α2-6**
Sialyllacyo-N-tetraose	**β1-4, α2-3, α2-6, β1-3**
Plant oligosaccharides	
Fructo-oligosaccharides	**β1-2**
Galacto-oligosaccharides	**β1-4, α1-6**
Transgalacto- oligosaccharides	**β1-4, β1-6**
Soybean oligosaccharides	**α1-2, α1-6**



Phylogenetic relationship of oligosaccharide content in primate milk



(Stewart & Disotell, 1998)

(Osthoff et al. 2010)

Synthesis of lactose and oligosaccharides

Glucose

ATP → ↓ → ADP

Glucose-6-phosphate + UTP

↓

UDP-Glucose

↓

UDP-Galactose

Glucose → ↓ Lactose synthetase (*β-4-galactosyltransferase I and α-lactalbumin*)

Lactose Gal β(1-4) Glc → SECRETION

Saccharides → ↓ Glucosyltransferase

Oligosaccharides Fuc α(1-2) Gal β(1-4) Glc

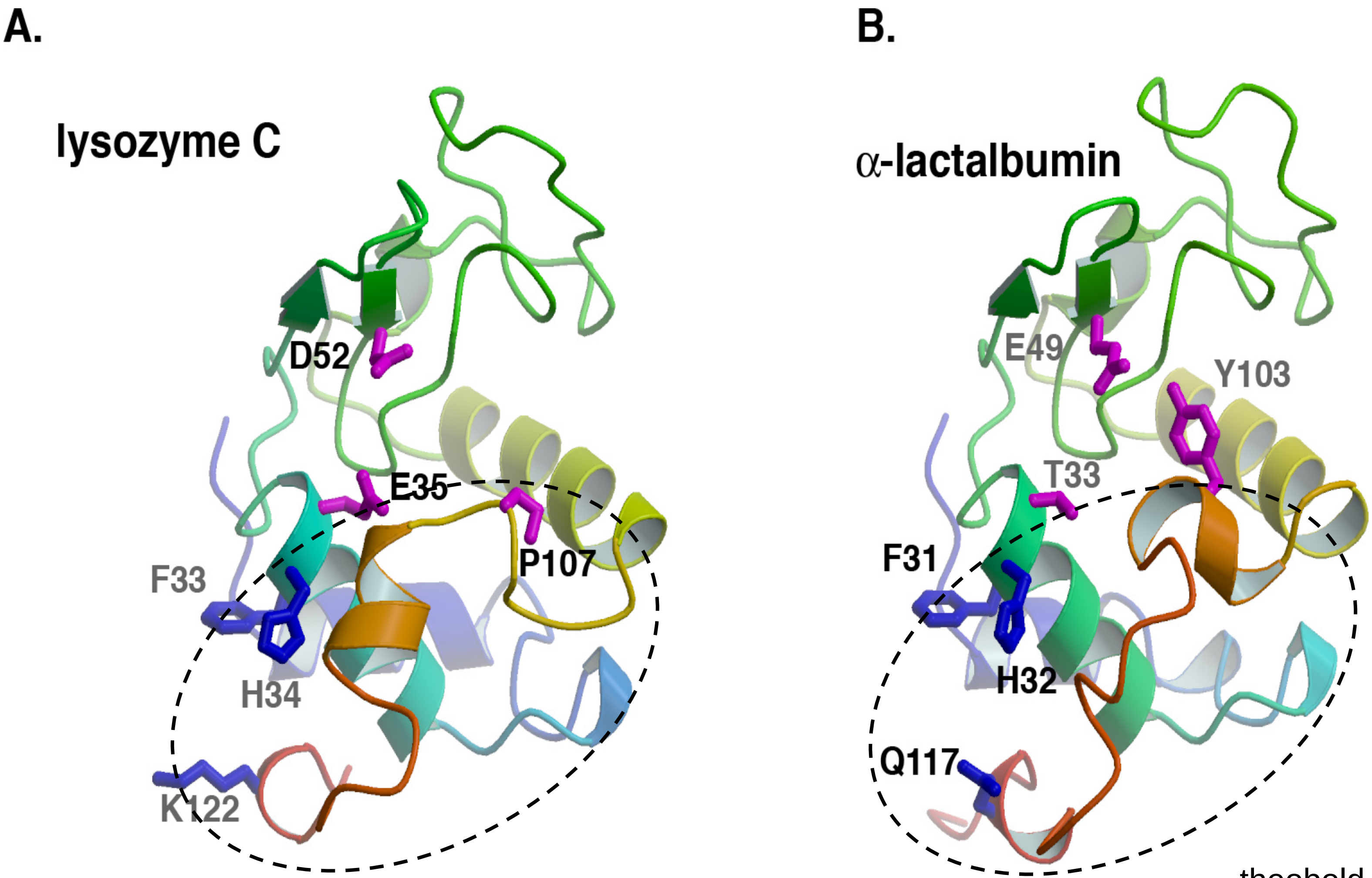
(Neville et al. 1983)

Alignment of the amino acid sequences of platypus and echidna α-lactalbumin and bovine lysozyme

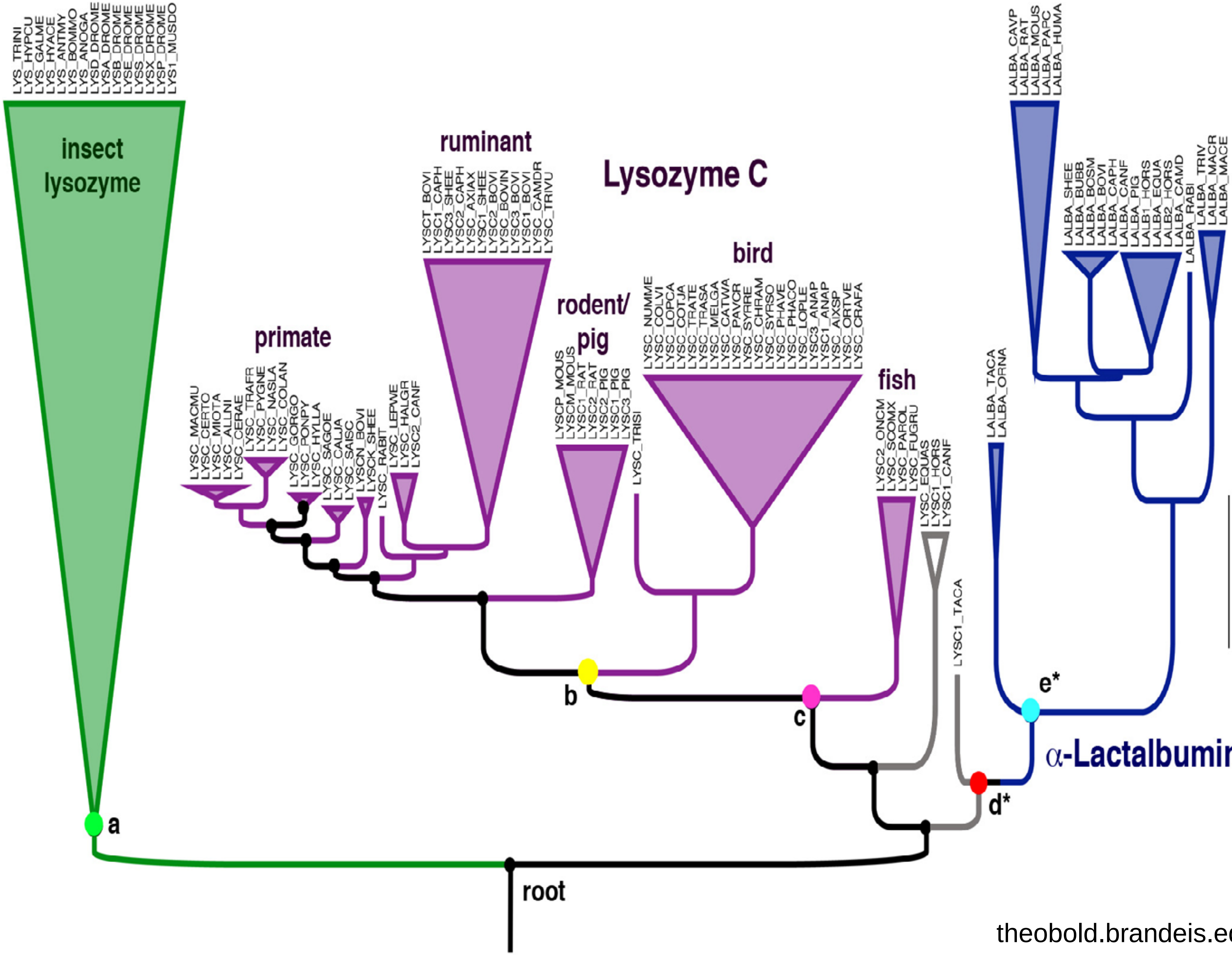
	1				50
Echidna	KVFEKCELSQ	MLKANGLDGF	QGITLEEWIC	IAFHESGFDS	RALNYY--NG
Platypus	RIFQICELSR	VLKENGLGGF	HGVSLEEWLC	VIFHESGYDS	QALNYY--NG
Cow	KVFERCELAR	TLKKLGLDGK	YGVSLANWLC	LTKWESSYNT	KATNYNPSSE
	51				100
Echidna	SSSHGLFQIN	RQYWCDGQDK	ASTEPSVNAC	QISCDKLRDD	DIEDDIKCVK
Platypus	SSSHGLFQIN	QPYWCDDXDS	ESTEPSVNAC	QIPCSKLLDD	DILDDIECAK
Cow	STDYGIFQIN	SKWWCN---D	GKTPNAVDGC	HVSCSELMEN	DIAKAVACAK
	101				150
Echidna	KILKESQGIT	AWEAWQPFCIA	D-LDQWK--C	--	
Platypus	KIVKEPKGIT	AWEAWQPFCNS	D-LDQWK--C	--	
Cow	HIVSE-QGIT	AWVAWKSHCRD	HDVSSYVEGC	TL	

(Messer et al. 1998)

Comparison of the 3-D structures of α-lactalbumin and lysozyme C



theobold.brandeis.edu

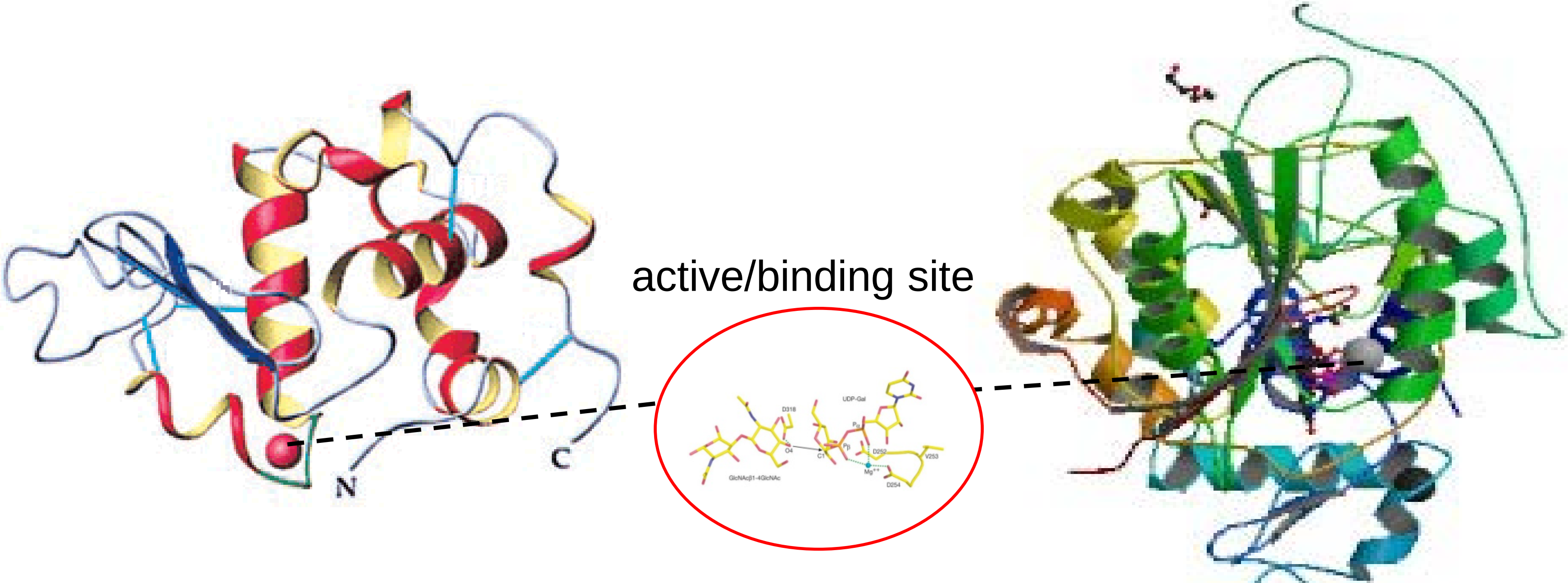


theobold.brandeis.edu

IDEA!?

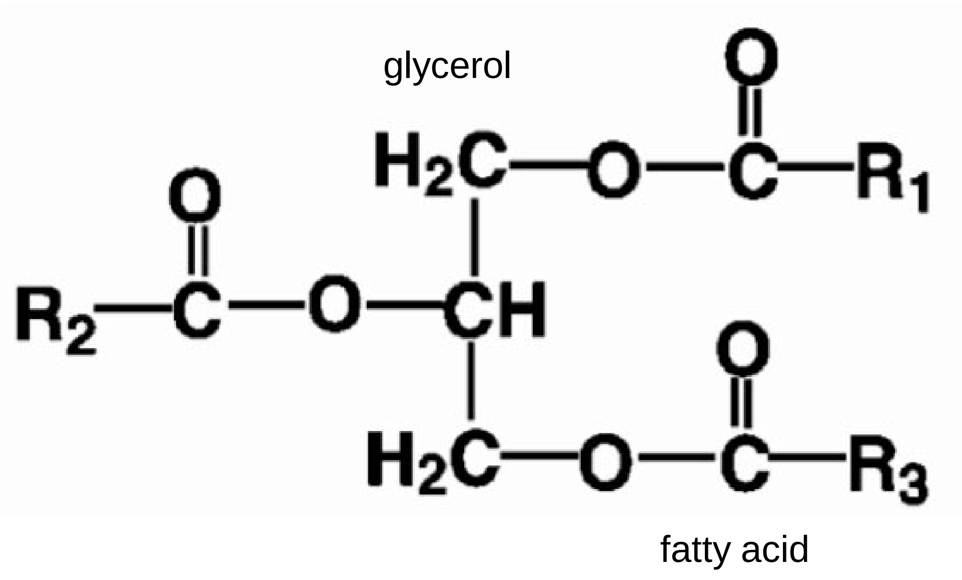
Comparative study of lactose release- and oligosaccharide synthesis enzymes:

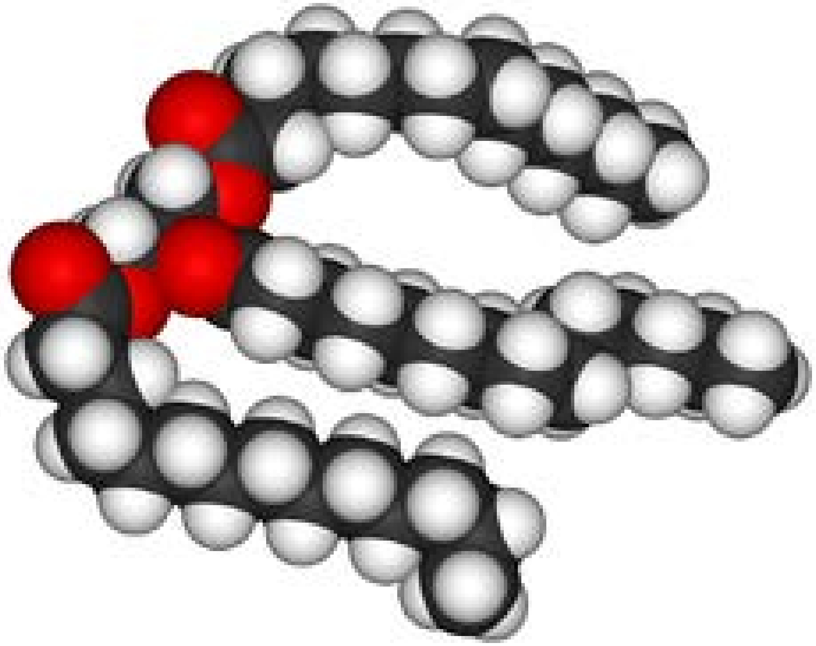
α-Lactalbumin Glucosyltransferase



(Ramakrishnan et al. 2005)

LIPIDS





Sources of fatty acids

(1) de novo synthesis

(2) the diet

(3) modification by desaturation and elongation

(essential: long chain + unsaturated)

(20:1 – 24:1)

(Hawke & Taylor 1983)

HUMAN MILK

Table 3. Distribution of fatty acids at sn-positions of human milk fat

Fatty acid (Mol %)	Sn-1	Sn-2	Sn-3
10:0	0.2	0.2	1.8
12:0	1.3	2.1	6.1
14:0	3.2	7.3	7.1
16:0	16.1	58.2	6.2
16:1	3.6	4.7	7.3
18:0	15.0	3.3	2.0
18:1	46.1	12.7	49.7
18:2	11.0	7.3	2.0
18:3	0.4	0.6	1.6
20:1	1.5	0.7	0.5

Typical fat molecule

Sn1 H_3C – C18:1

Sn2 H_2C – C16:0

Sn3 H_3C – C18:1

Secondary fat molecules

Sn1 H_3C – C18:2 Essential FA's

Sn2 H_2C – C16:0

Sn3 H_3C – C12:0 Short FA's

(Christie 1983)

Digestion in 3 phases

1. Pre-duodenal lipase acts on sn-3

Sn1 H_3C – C18:1
Sn2 H_2C – C16:0
Sn3 H_3C – C18:1

→

Sn1 H_3C – C18:2
Sn2 H_2C – C16:0
Sn3 H_3C – OH

2. Pre-duodenal pancreatic lipases act on sn-1 & sn-3

Sn1 H_3C – C18:1
Sn2 H_2C – C16:0
Sn3 H_3C – C18:1

→

Sn1 H_3C – OH
Sn2 H_2C – C16:0
Sn3 H_3C – OH

Antimicrobial
Increase absorption of FA's

3. Breast milk lipase act on sn-1, sn-2, sn-3
Bile salt stimulated in duodenum

(Lien et al 1997; Lien & Lucas 1997)

Fatty acids at sn-positions: human and cow's milk fat

	HUMAN			COW		
Fatty acid (Mol%)	Sn-1	Sn-2	Sn-3	Sn-1	Sn-2	Sn-3
C4:0				-	-	5.47
C6:0				4-	0.9	12.9
C8:0				1.4	0.7	3.6
10:0	0.2	0.2	1.8	1.9	3.0	6.2
12:0	1.3	2.1	6.1	4.9	6.2	0.6
14:0	3.2	7.3	7.1	9.7	17.5	6.4
16:0	16.1	58.2	6.2	34.0	32.3	5.4
16.1	3.6	4.7	7.3	2.8	3.6	1.4
18:0	15.0	3.3	2.0	10.3	9.5	1.2
18.1	46.1	12.7	49.7	30.0	18.9	23.1
18.2	11.0	7.3	2.0	1.7	3.5	2.3
18.3	0.4	0.6	1.6			
20:1	1.5	0.7	0.5			

(Christie 1983)

FA's not in correct sn-position. May lead to difficiencies.
Limiting is the essential FA's

Human

Sn1 H_3C – C18:1 Essential FA's
Sn2 H_2C – C16:0
Sn3 H_3C – C18:1 Short FA's

Typical Cow's fat

Sn1 H_3C – C16:0/C18:1
Sn2 H_2C – C16:0
Sn3 H_3C – C18:1/C6:0

FAT SOURCES FROM PLANT MATERIAL IN FORMULAS

Corn oil
Safflower oil
Coconut oil
High oleic sunflower oil

Soy oil
Palm oil
Free fatty acids (essential)
Single cell oil

FA's not in correct sn-position. May lead to difficiencies.
Limiting is the essential FA's

HUMAN

Sn1 H_3C – C18:1 Essential FA's
|
Sn2 H_2C – C16:0
|
Sn3 H_3C – C18:1 Short FA's

TYPICAL PLANT FAT

Sn1 H_3C – C18:1
|
Sn2 H_2C – C18:2 Essential FA's
|
Sn3 H_3C – C18:1

Lesson:

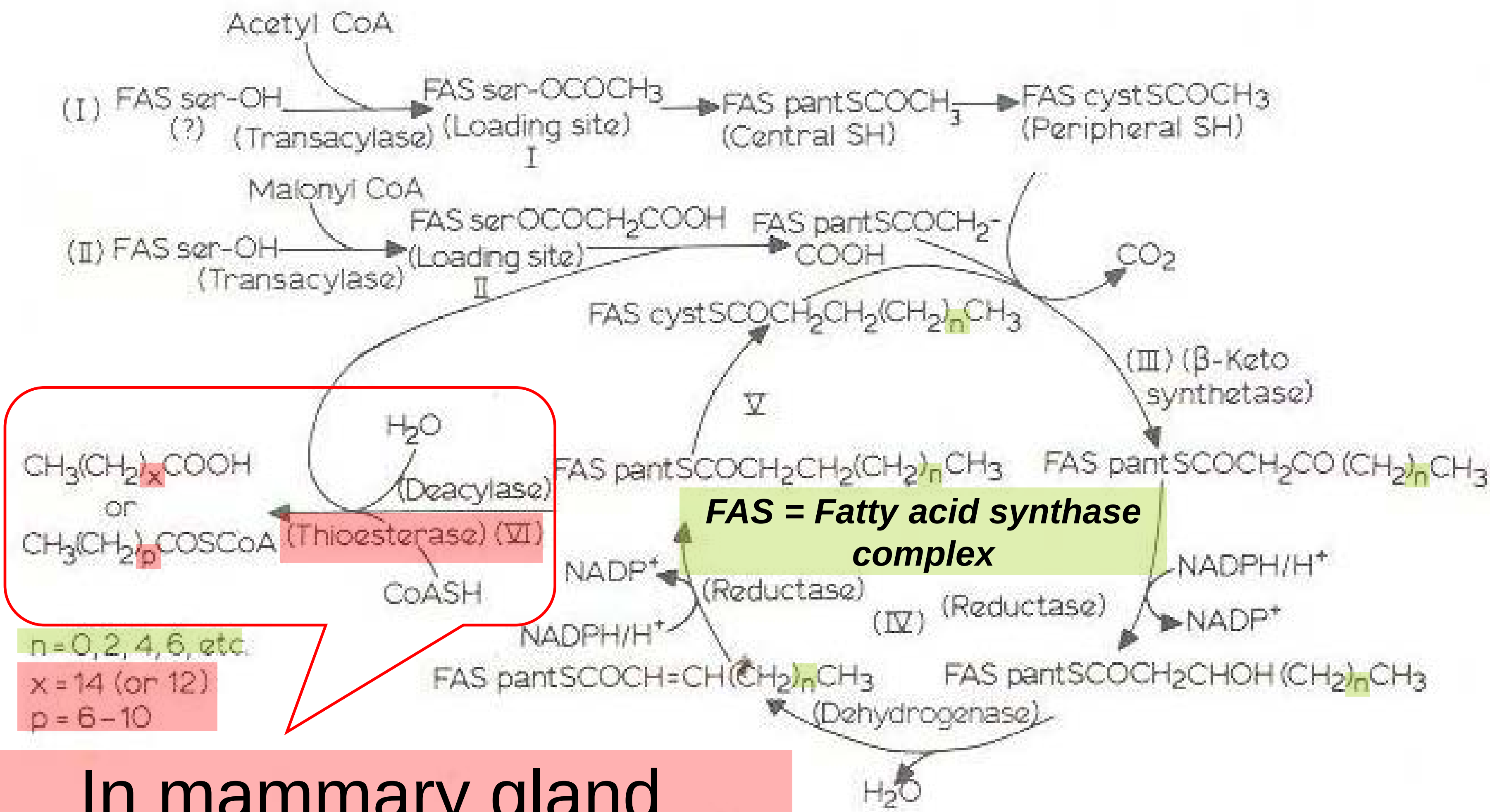
If FA's not in correct sn-position: May lead to deficiencies
Fat absorption is very efficient
Essential FA's can be added

Fatty acid composition (% of total FA's) of the fat fraction of milks

Fatty acid	Human	Cow	Springbok	Blue W Beest	White Rhino	Elephant	Cheetah
C4:0	0	3.3	0.7	0.2	0	0	0
C6:0	0	1.6	0.7	2.0	0	0	0
C8:0	0.4	1.3	0.5	5.6	3.0	2.9	0
C10:0	1.0	3.0	0.9	20.7	25.5	35.3	0
C11:0						1.2	0
C12:0	4.4	3.1	1.3	9.0	16.5	26.9	0.1
C13:0			0.1			0.3	2.7
C14:0	6.3	9.5	13.4	20.6	9.6	0.5	
C15:0			1.3	1.2	0.4	0.2	0.3
C16:0	22.0	26.3	21.3	21.5	15.8	9.5	21.0
C16:1c9	3.3	2.3	1.7	0.6	1.2	1.0	5.8
C17:0			1.6	1.2	0.5	0.3	0.4
C17:1c10			0.2			0.3	0.4
C18:0	8.1	14.6	17.2	5.5	8.9	1.4	4.5
C18:1c9	31.3	29.8	25.1	8.1	8.6	11.3	32.4
C18:c7						2.1	
C18:2c9,12(n-6)	10.8	2.5	3.0	1.6	3.7	0.9	15.3
C18:3c9,12,15(n-3)	0.8	2.5	1.2	0.6	2.5	0.8	10.1
C18:3c6,9,12 (n-6)	0.2		0.1			-	0.1
C20:0				0.6	0.4	0.1	0.3
C20:2c11,14 (n-6)	0.3		0.1			0.1	
C20:3c8,11,14 (n-6)	0.3					0.2	
C20:3c11,14,17 (n-3)						0.1	1.1
C20:4c,5,8,11,14 (n-6)	0.4						
C20:5c5,8,11,14,17 (n-3)	01						
C22:6c4,7,10,13,16,19(n-3)	0.2						

Osthoff et al. 2005;2006; 2007, 2008; 2009)

Fatty acid synthesis



In mammary gland

***Thioesterase* determines length**

C8 – C14

Hawke & Taylor 1983

Phylogenetic relationship of fatty acid composition in primate milk

Vervet monkey
Macaque
} *Cercopithecidae*

Oligosaccharides low
8:0, 10:0 high
14:0 low

WH Gibbon *Hylobatidae*

Oligosaccharides low
8:0, 14:0 low
10:0 high

} *Hominoidea*

8:0 low

Gorilla
Human
} *Hominidae*

Oligosaccharides high
8:0, 10:0 low
14:0 high

(Osthoff et al. 2010)

Metabolic disorder

- **Defective acylCoA dehydrogenase**

- Defective short chain acylCoA dehydrogenase
- Defective medium chain acylCoA dehydrogenase
- Defective long chain acylCoA dehydrogenase
- Defective very long chain acylCoA dehydrogenase (Adrenoleukodystrophy)

(Spiekerkoetter et al. 2003; Kompare & Rizzo 2008)

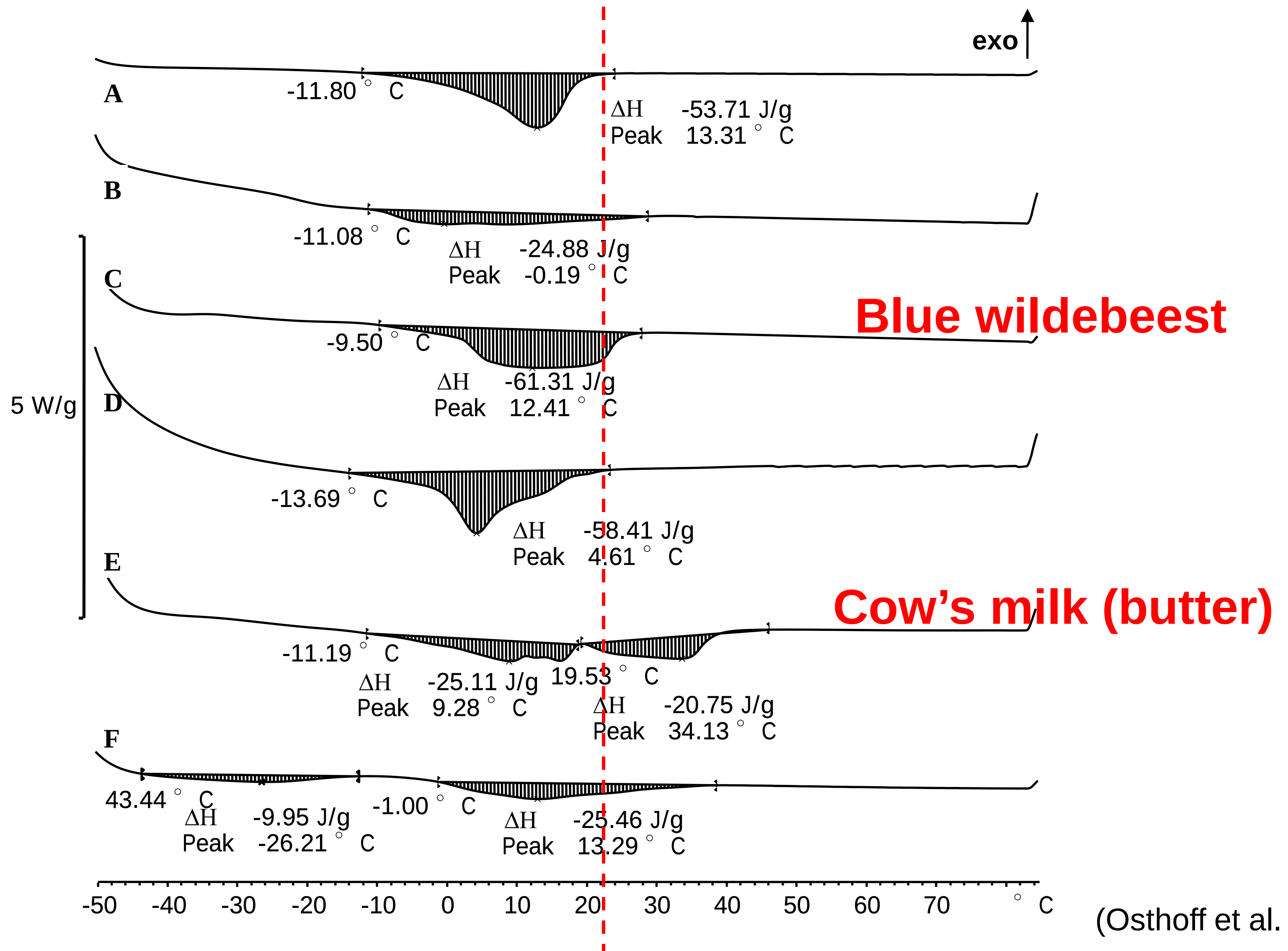
Fatty acid composition (% of total FA's) of the fat fraction of milks. Cattle grazed on same vegetation type

	Boran	Nguni	Tuli	Bonsmara	Drakensb	Afrik.	Signif.
	n =5	n = 9	n = 10	n=6	n=6	n=6	
C4:0	0.70 ± 0.16^{ab}	0.49 ± 0.32^{a}	0.41 ± 0.34^{a}	0.96 ± 0.09^{b}	0.95 ± 0.13^{b}	0.97 ± 0.10^{b}	$p < 0.001$
C6:0	0.99 ± 0.22^{ab}	0.75 ± 0.39^{a}	0.73 ± 0.35^{a}	1.33 ± 0.15^{b}	1.41 ± 0.27^{b}	1.23 ± 0.19^{b}	$p < 0.001$
C8:0	0.71 ± 0.20^{ab}	0.62 ± 0.29^{a}	0.67 ± 0.12^{a}	1.07 ± 0.15^{bc}	1.28 ± 0.20^{c}	1.00 ± 0.17^{bc}	$p < 0.001$
C10:0	1.68 ± 0.62^{ab}	1.62 ± 0.52^{ab}	1.56 ± 0.33^{a}	2.79 ± 0.68^{cd}	3.43 ± 0.57^{d}	2.41 ± 0.44^{bc}	$p < 0.001$
C12:0	2.26 ± 0.73^{ab}	2.11 ± 0.63^{a}	2.06 ± 0.41^{a}	3.55 ± 0.75^{cd}	4.33 ± 0.53^{d}	3.04 ± 0.43^{bc}	$p < 0.001$
C14:0	10.01 ± 1.08^{ac}	9.43 ± 2.15^{ab}	8.60 ± 1.09^{a}	12.72 ± 1.68^{cd}	14.50 ± 0.97^{d}	11.50 ± 1.34^{bc}	$p < 0.001$
C18:1c9	26.96 ± 2.84^{bc}	27.77 ± 7.11^{c}	30.39 ± 4.50^{c}	20.03 ± 3.44^{ab}	14.84 ± 1.53^{a}	20.27 ± 3.23^{ab}	$p < 0.001$
C18:1c7	0.29 ± 0.09^{ab}	0.26 ± 0.12^{ab}	0.42 ± 0.19^{b}	0.22 ± 0.07^{ab}	0.20 ± 0.10^{a}	0.29 ± 0.14^{ab}	$p < 0.05$
Saturated FA's	63.99 ± 4.33^{ac}	63.72 ± 8.58^{ab}	60.88 ± 4.72^{a}	72.80 ± 4.30^{cd}	78.41 ± 2.32^{d}	71.87 ± 3.72^{bcd}	$p < 0.001$
Mono Unsat FA's	33.22 ± 3.81^{bcd}	33.22 ± 7.69^{cd}	36.47 ± 5.06^{d}	24.38 ± 3.84^{ab}	19.91 ± 2.12^{a}	25.67 ± 3.62^{ac}	$p < 0.001$
Total Omega-3 FA's	0.38 ± 0.14^{ab}	0.60 ± 0.35^{b}	0.45 ± 0.20^{ab}	0.76 ± 0.11^{b}	0.23 ± 0.18^{a}	0.54 ± 0.09^{ab}	$p < 0.01$

(Myburgh et al. in preparation)

Differential Scanning Calorimetry thermograms of milk fat from various mammals.

African elephant (A), cheetah (B), blue wildebeest (C), vervet monkey (D), domestic cow (E) and bottlenose dolphin (F)

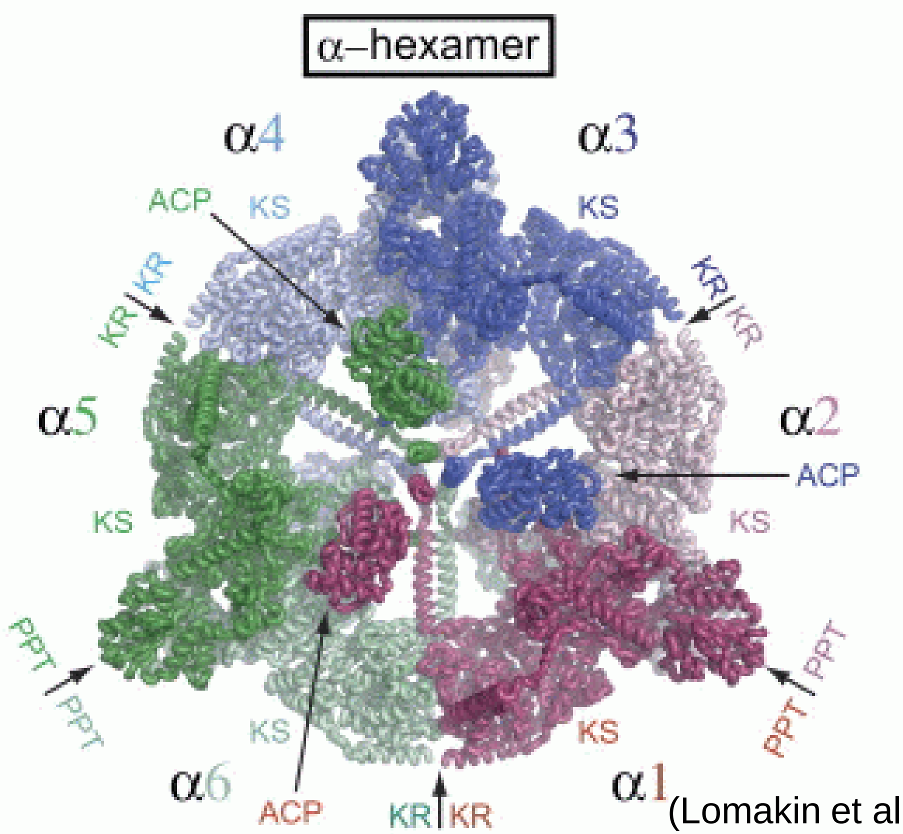


(Osthoff et al. 2011)

IDEA!?

Comparative study of fatty acid synthesis enzymes :

Fatty acid synthase



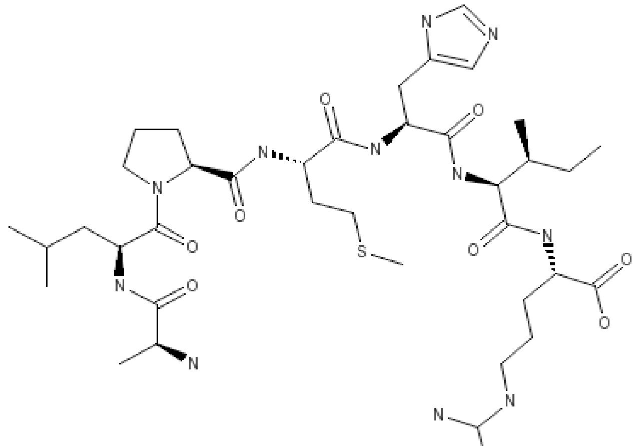
(Lomakin et al. 2007)

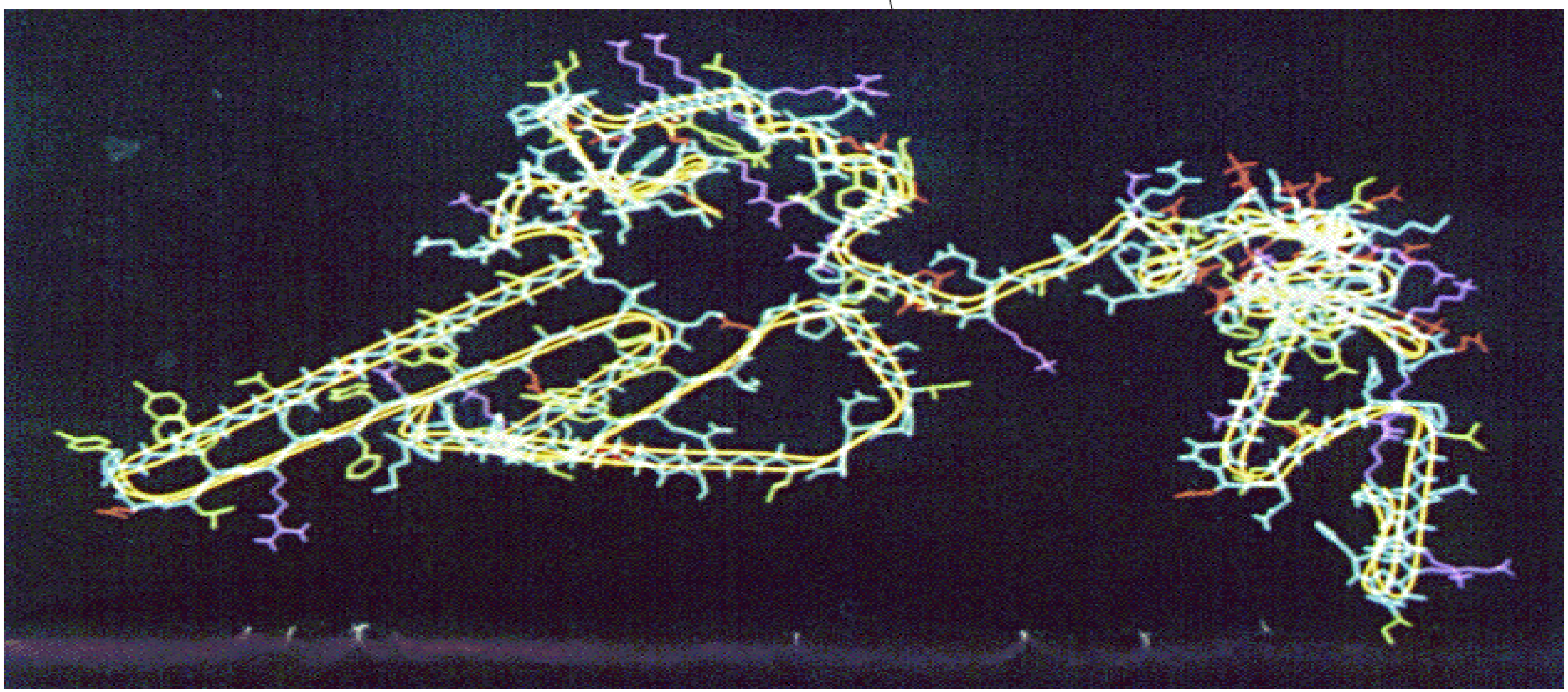
Thioesterase

[trimer]

(Lehtia et al. 2007)

PROTEINS





Milk proteins

Caseins (2.6%)
- **αs1-casein**
- **β-casein**
- **κ-casein**
- **αs2-casein**

Posttranslational modifications

Glycosylation phosphorylation disulphide bond proteolysis

genetic variants

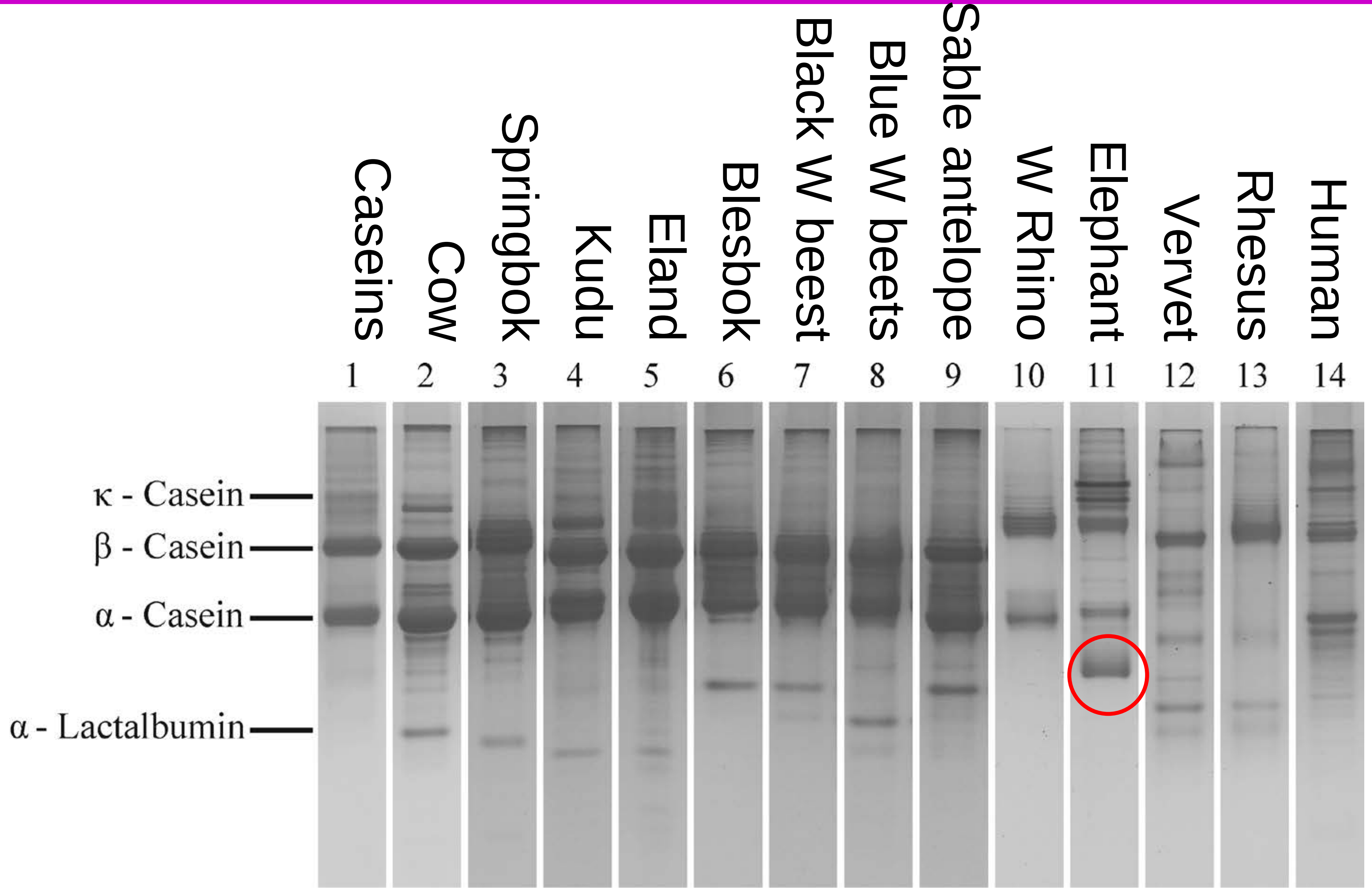
Whey (0.7%)
- **β-lactoglobulin**
- **α-lactalbumin**
- **serum albumin**
- **immunoglobulins**

Minor proteins

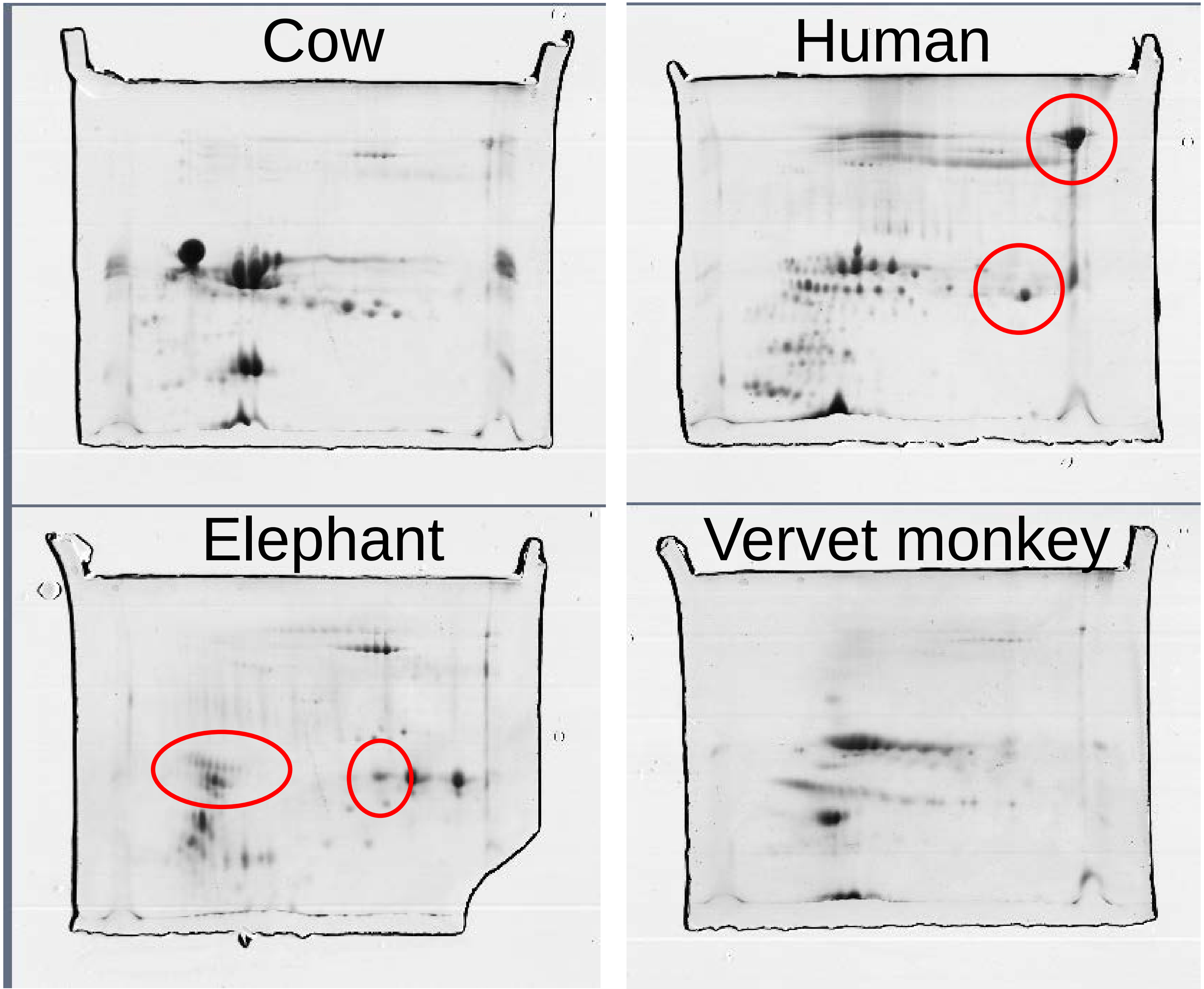
lipocalin-type prostaglandin d synthase, fatty acid binding protein, b2-microglobulin, complement C4, clusterin, a1-antritrypsin, lysozyme C, prealbumin, serotransferrin, fructose-bisphosphate aldolase A

Etc. etc. etc. etc. etc……..unknown?!

Milk proteins by electrophoresis



Proteins by 2-D electrophoresis



IDEA!?

Comparative proteome and protein modelling:

Enzymes in fatty acid synthesis:

Fatty acid synthetase

Thioesterase

Enzymes in lactose release and oligosaccharide synthesis:

α-Lactalbumin

Glucocyltransferase

FUTURE?

Explain the biochemical reason why milk of some mammals contains high amounts of oligosaccharides.

Explain the biochemical reason of the synthesis of different fatty acid chain lengths amongst mammals.

DISTANT FUTURE?

Genetic manipulation of commercial dairy animals to produce custom milk:

Oligosaccharide enriched

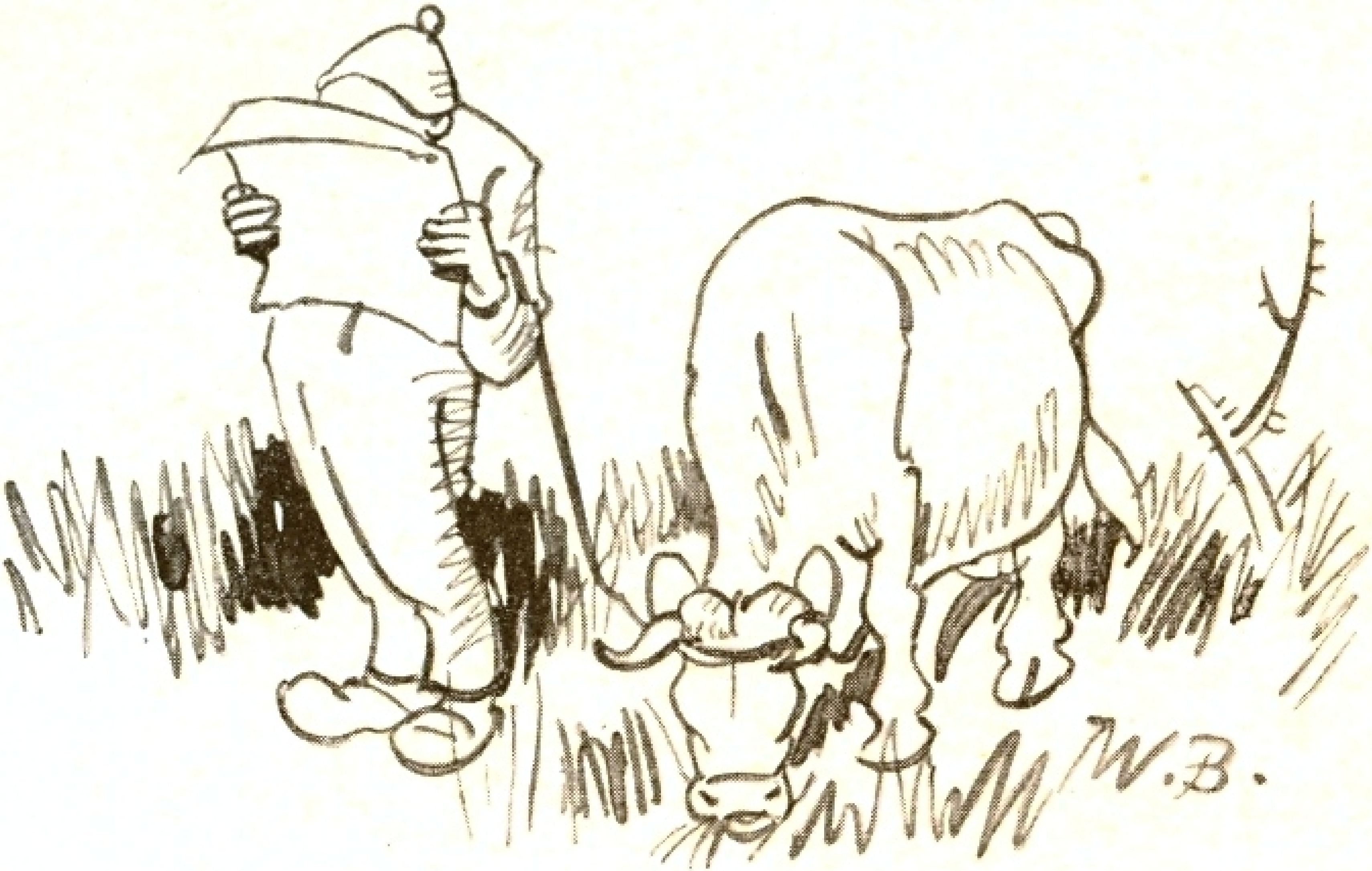
Custom Fat

soft butter

improved digestibility

(for metabolically impaired)

Studying milk…



Danke/Dankie/Thank you/Ke a leboha

Acknowledgements/Bedankings/Danksagungen

Meine Eltern

Therese & Merlind

My colleagues (Food Science Section, Department, University)

My students

Desiré Harris

The late Anita vd Westhuizen

Joan Nel, Stephen Collet

UFS

… surprising results

Danke/Dankie/Thank you/Ke a leboha