Adaptation of dromedary camels to harsh environmental conditions in arid and semi-arid zones

Effect of environmental conditions to production and reproduction

Nagy Péter

Emirates Industries for Camel Milk & Products

Dubai, UAE - Budapest

"Camelids as emerging food producing species in our changing climate"

Camelid WG Session at the 70th Annual Meeting of EAAP

29 August 2019

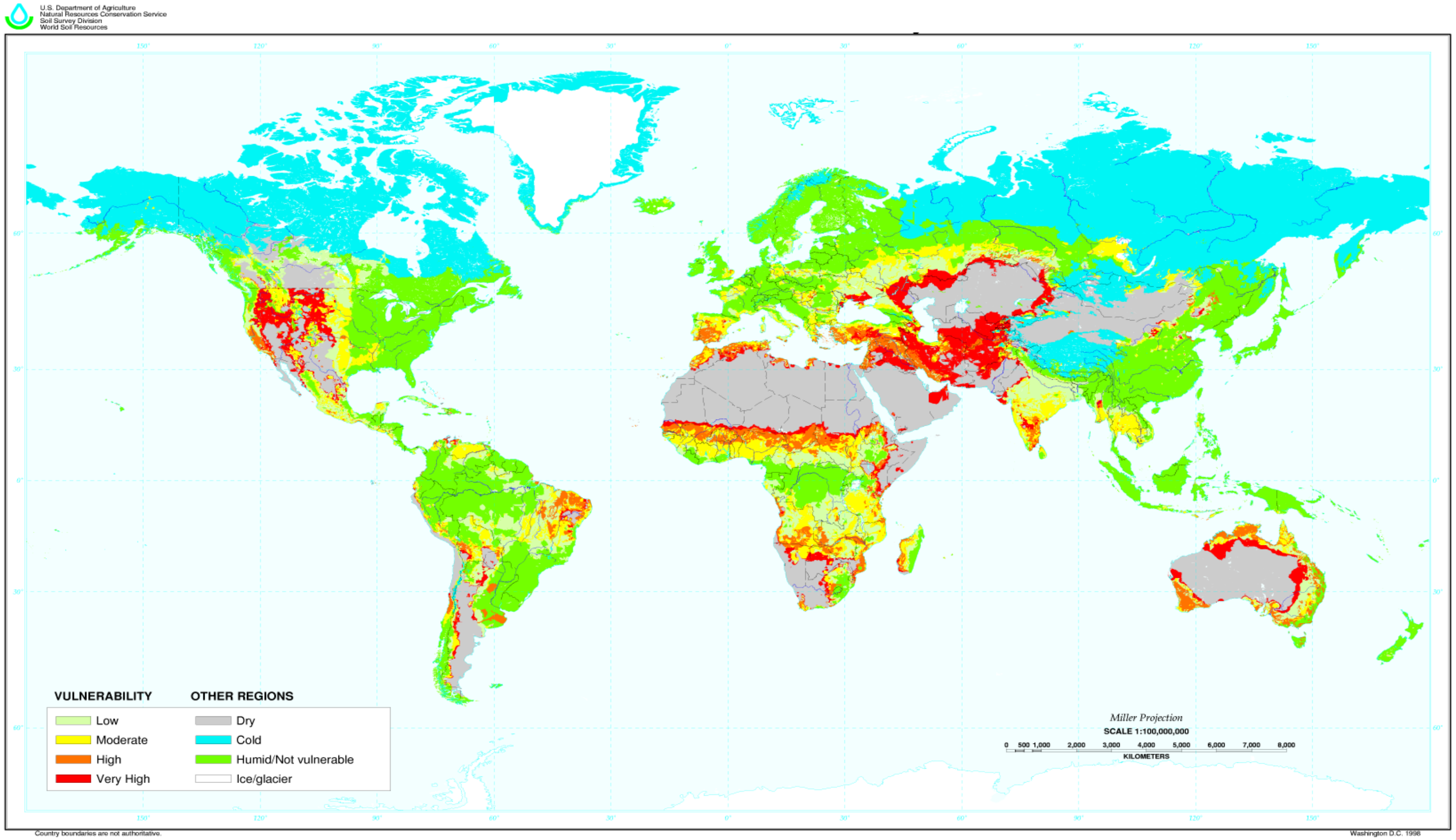
Prof. Kristina Dahlborn
Dept of Anatomy, Physiology and Biochemistry, SLU, Uppsala, Sweden

Global trends

- Climate change
  - Increasing temperatures
  - changing weather patterns, droughts and inundating rains
- **Desertification**
- Reduction in overall world crop yields
- Decrease in food and feed grain availability (biofuel production)
- Difference between projected requirement of food supply and available resources by 2030-2040
- Expected change in animal production systems
  - Crop residue based ruminant and other herbivore production system in developing countries (app. 3.3 billion cattle, sheep and goat)

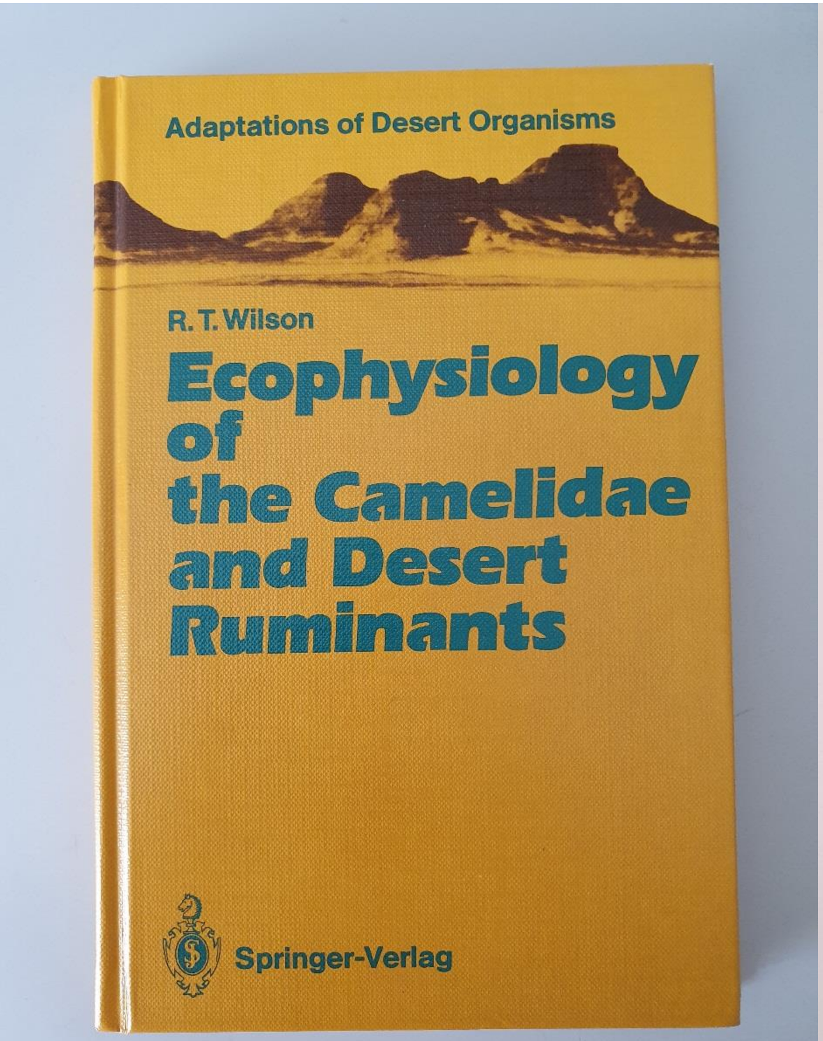
Leng, 2010

Desertification Vulnerability

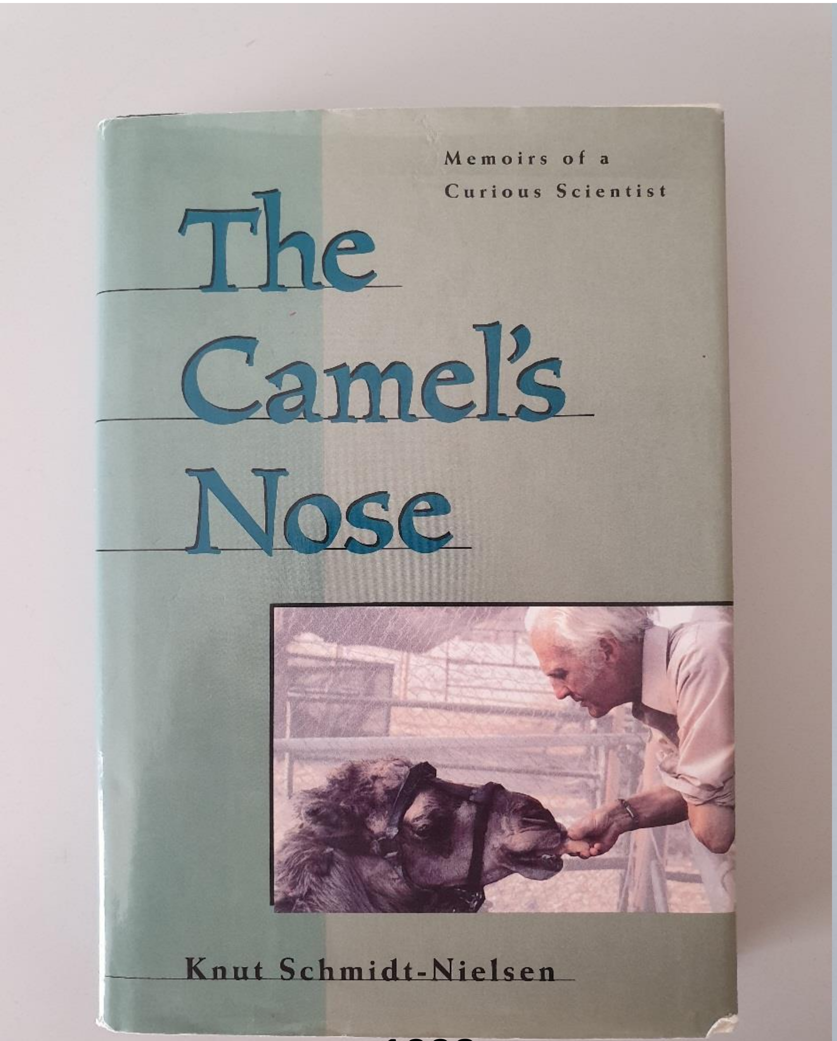


- 40% of Earth's land is covered by drylands, and these areas are home to over 2 billion people.
- 12 million hectares of productive land become barren every year due to desertification and drought as a result of human activity and/or climate change

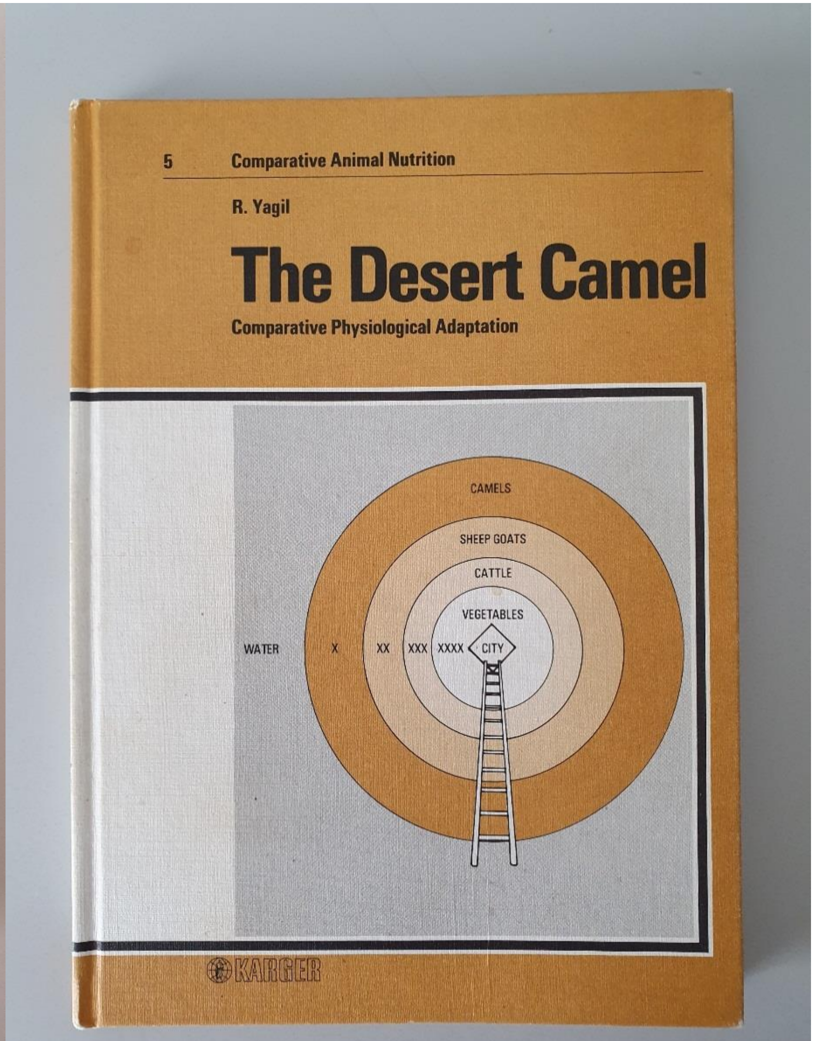
Important books on physiology and adaptation of camels to the desert environment



1989

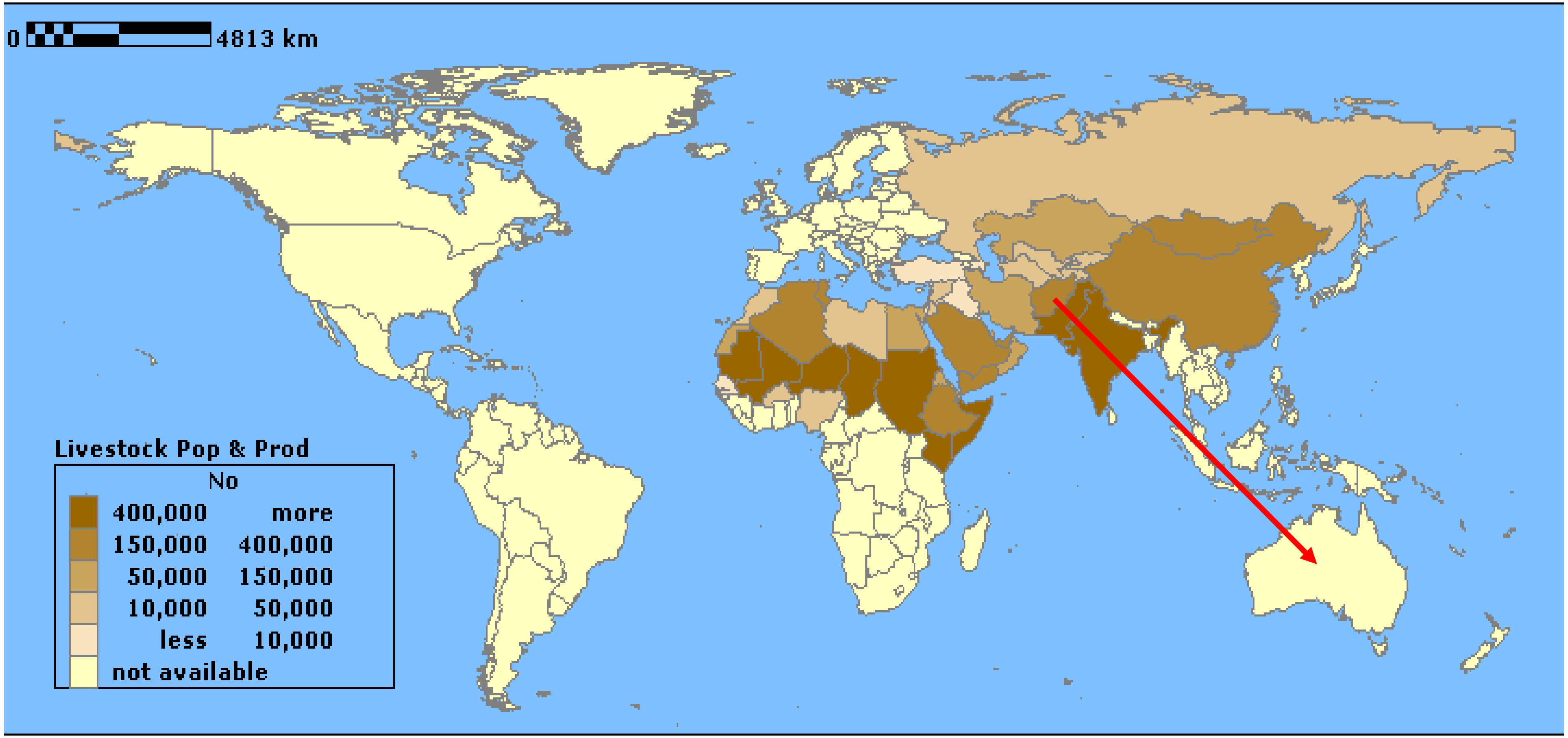


1998



1985

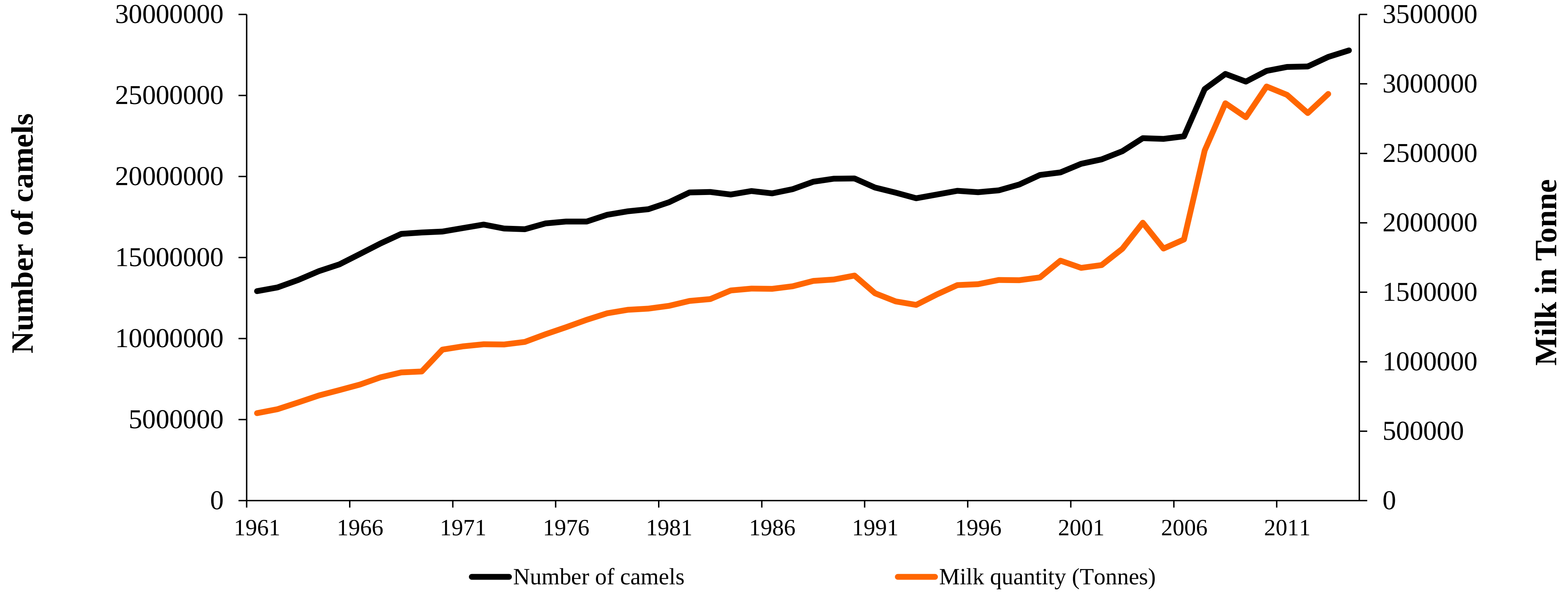
Camel population in the World



Bactrians and dromedaries are native in 47 countries in the World

Faye, 2009

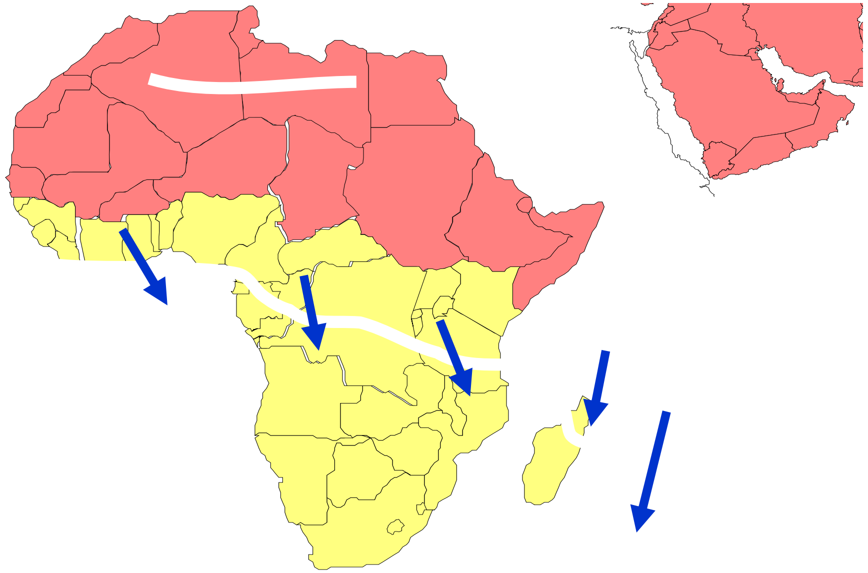
Changes in camel population and milk production from 1961 to 2014



- Camel population ⇑ 2.2x since 1961 (2.1 % per year)
- Milk production ⇑ 4.6x since 1961 (6.9 % per year)

FAOSTAT Date: Mon Sep 05 14:20:48 CEST 2016

Extension of camel farming in Africa



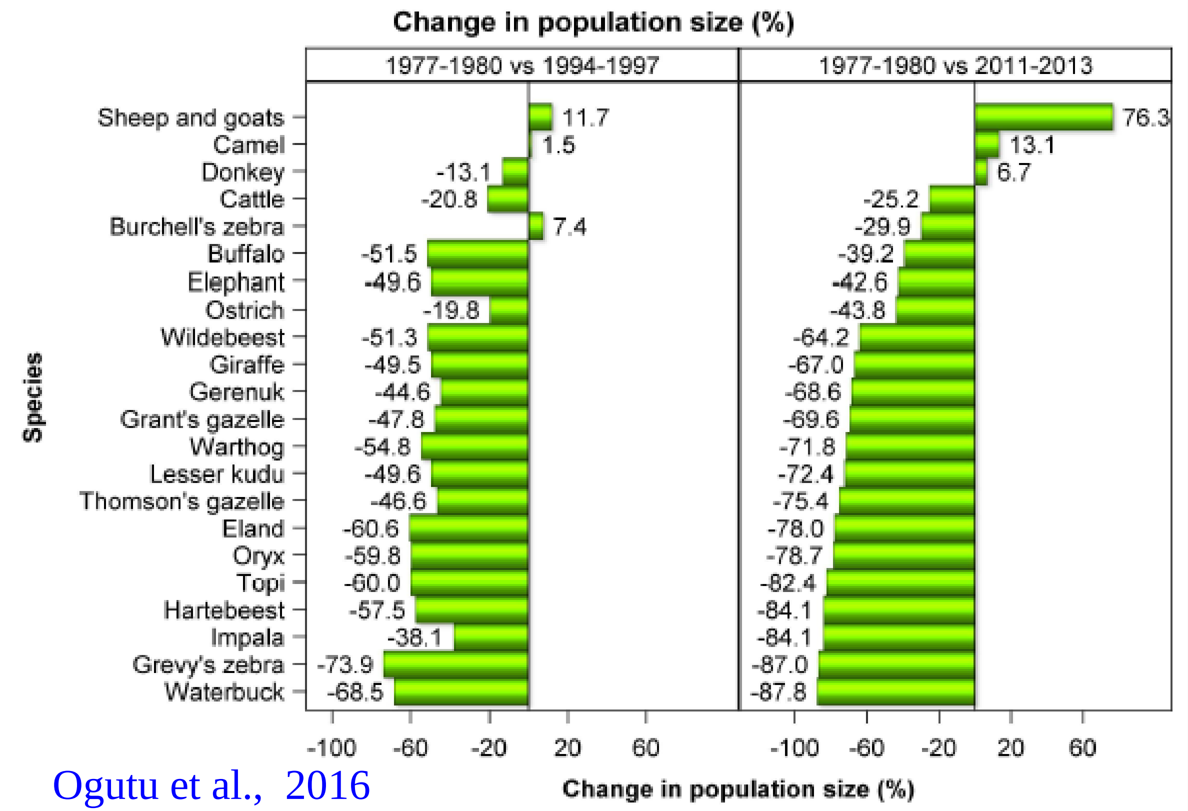
Camel farming is developing in Nigeria, CAR, Uganda, Tanzania

SHORT REPORT Open Access

Camel rearing replacing cattle production among the Borana community in Isiolo County of Northern Kenya, as climate variability bites

Anastasia W Kagunyu[1*] and Joseph Wanjohi[2] 2014

Extreme Wildlife Declines and Concurrent Increase in Livestock Numbers in Kenya: What Are the Causes?



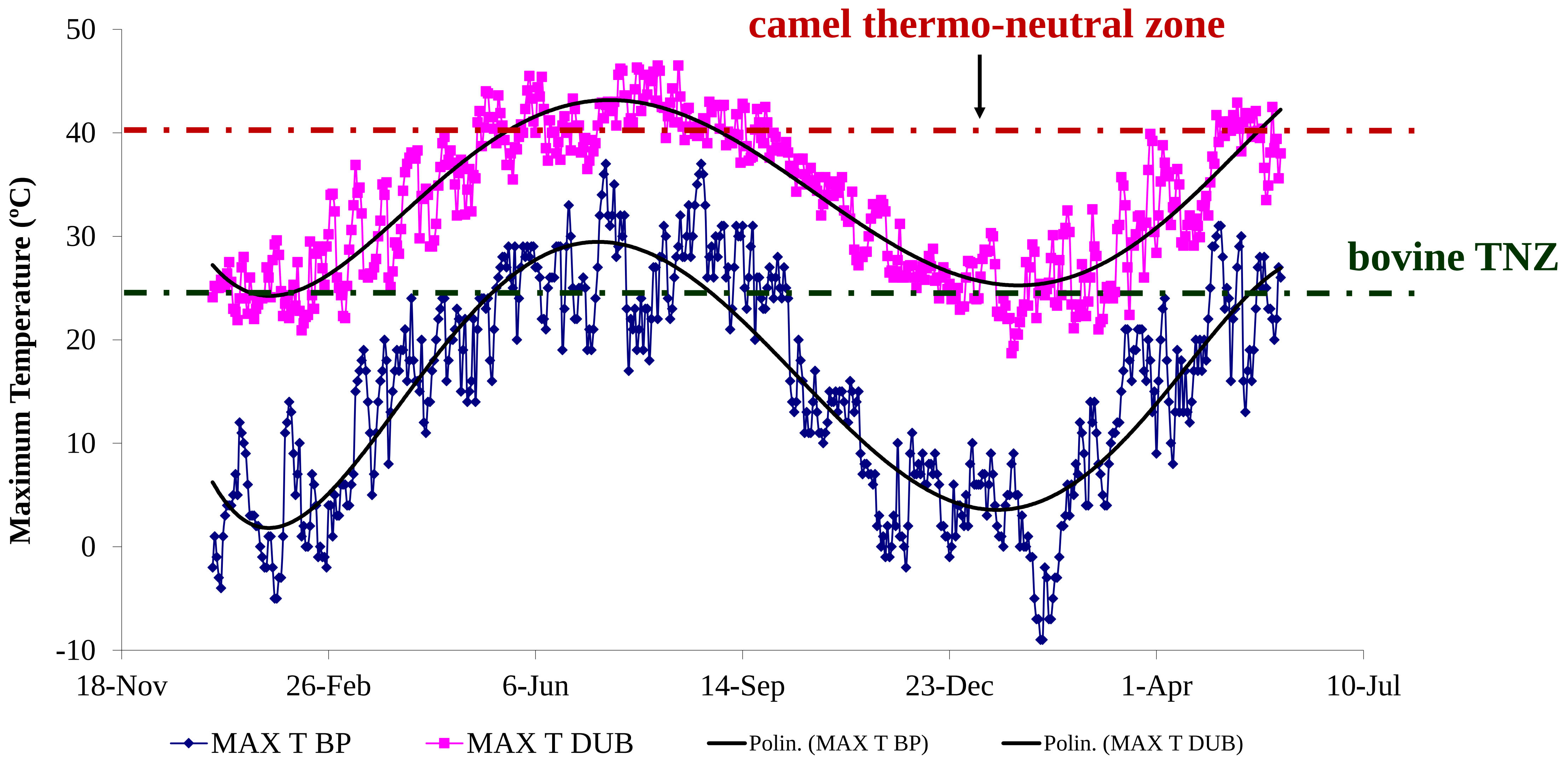
Ogutu et al., 2016

Adaptation strategies

Physiology, Anatomy, Behavior - biological reasons for growth

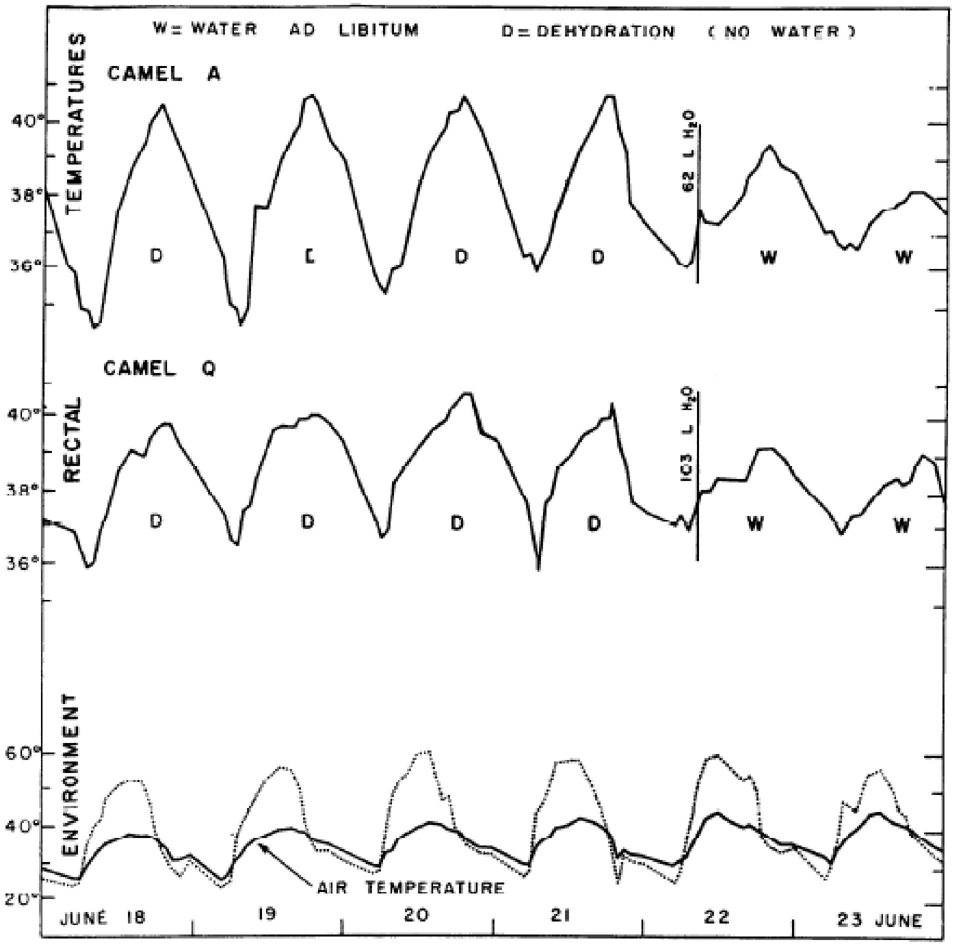
- Anatomy and physiological mechanisms to tolerate **high heat loads**
    - high ambient temperature
    - water scarcity
    - ability to withstand dehydration
- Ability to utilize **marginal feed sources** and high salt-content plants (halophytes)
- High feed conversion efficiency (?)

Annual changes in maximum temperature in continental climate (Budapest) and in desert environment (Dubai)



Diurnal variation in body temperature
dehydrated vs. hydrated camels

- During water deprivation
  - **6.2 ºC** (34.5 to 40.7 ºC)
  - decrease in early morning
- If access to water (or in winter)
  - **2 ºC** (36 to 38 ºC)
- Advantages of high body temperature
  - storage of heat: 500 kg animal stores **2,500 kcal** (10.5 MJ) heat
  - decrease of evaporation: equivalent to the evaporation of **5 liters of water**
  - reduction in heat flow from the environment
- Metabolic rate is decreased in dehydration, but increased by high temperature



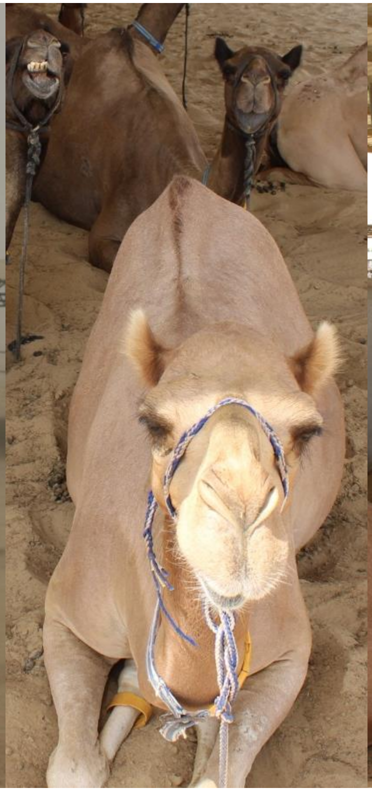
Schmidt-Nielsen et al., 1956

Insulation of the camel: the fur and skin pads

- Skin is thin and highly vascularized
- Camels have sweat follicles and do sweat
- Evaporation is not visible from the skin

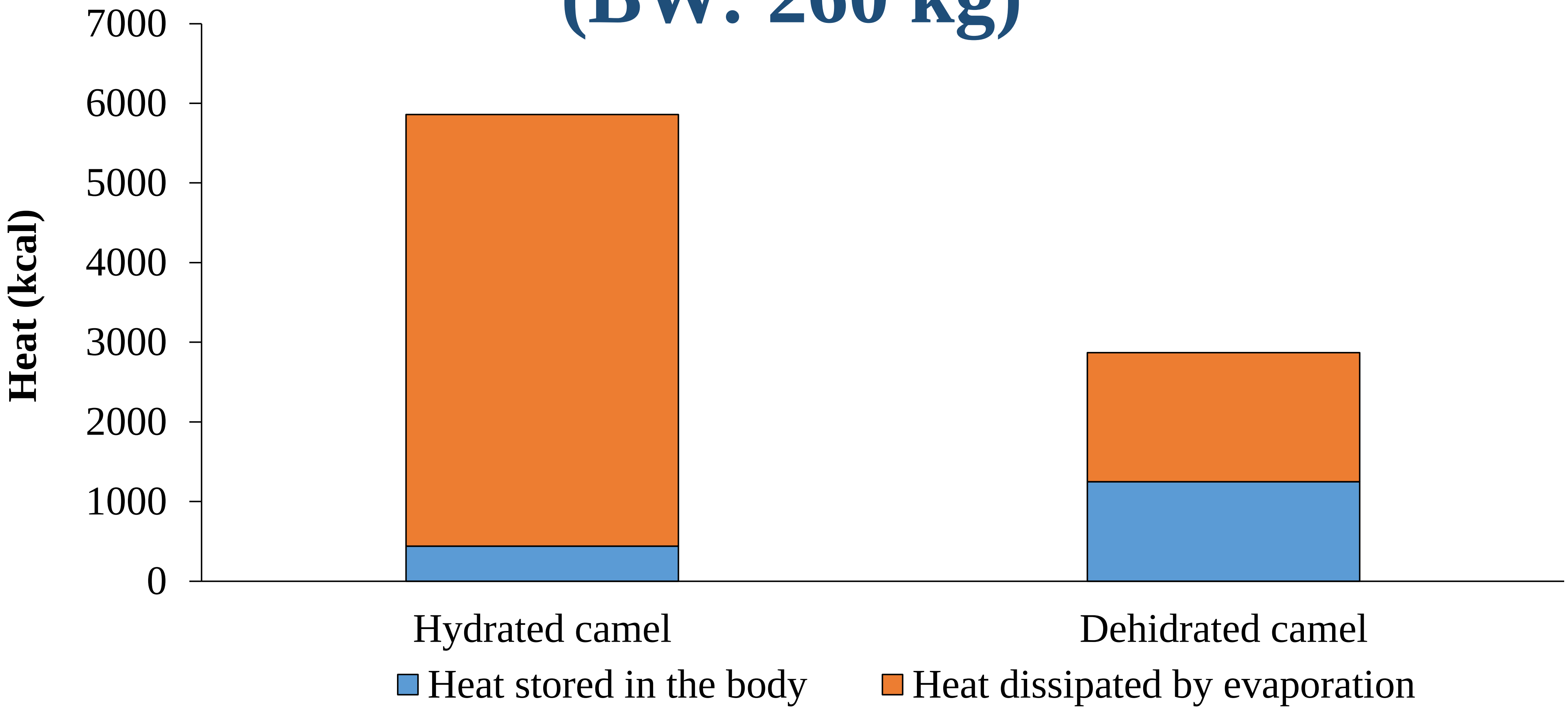
- Subcutaneous fat limited
- Fur shedding is in the autumn, hair follicle cycle has a **seasonal pattern** with peak in the summer-autumn

Unique behavior in the desert



- Camels expose smallest possible body surface area to the radiation from the sun
- They tend to sit in groups and in the same place for long time

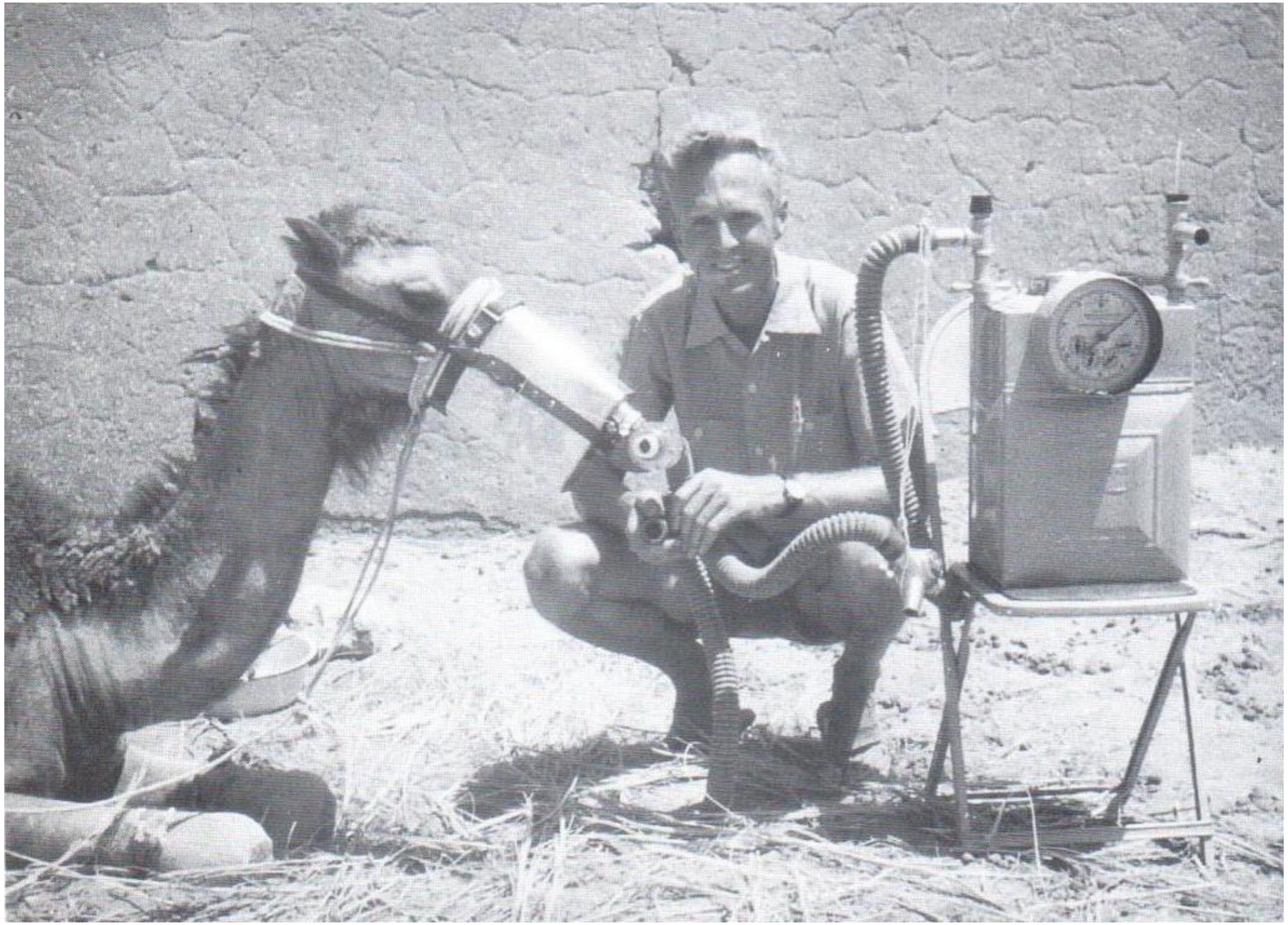
Total heat load of hydrated and dehydrated camels (BW: 260 kg)



Dehydrated camels reduce heat flow from the environment by 50 %

Schmidt-Nielsen, 1964

Nose of the camel and ventilation



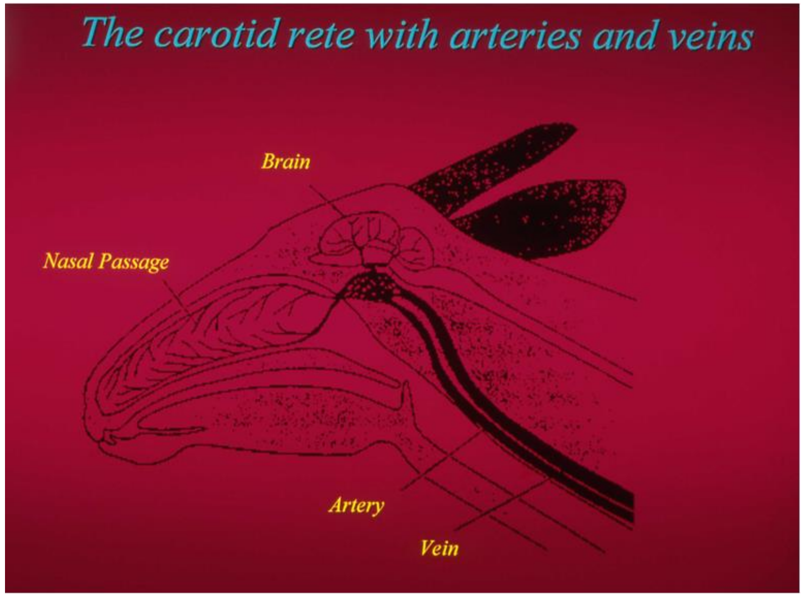
Schmidt-Nielsen et al., 1981

Nose of the camel and ventilation

- Respiration rate
  - 6 -11/min. (avg: 8) morning
  - 8-18/min. (avg: 16) during the day
  - in dehydrated camels 4.3/min.
- Surface area of turbinate structures is much larger than in humans (**1000 cm^2** vs. 12 cm^2)
- Wall-to-wall distance (the width of the passageways) is much smaller than in humans
- In hydrated and mildly dehydrated camels **exhaled air is saturated** (100 % r.h.)
- In severely dehydrated camels, **exhaled air is unsaturated** (75 % r.h.) with extremely low respiratory water losses
- Respiratory water loss is **reduced by cooling** of the exhaled air and by a simple exchange system based on the **dry, hygroscopic nasal surface** in dehydrated animals
- Recovery of water caused by nasal heat exchange might reach **70 %** of the potential respiratory water loss

Schmidt-Nielsen et al., 1981

Cooling of the brain

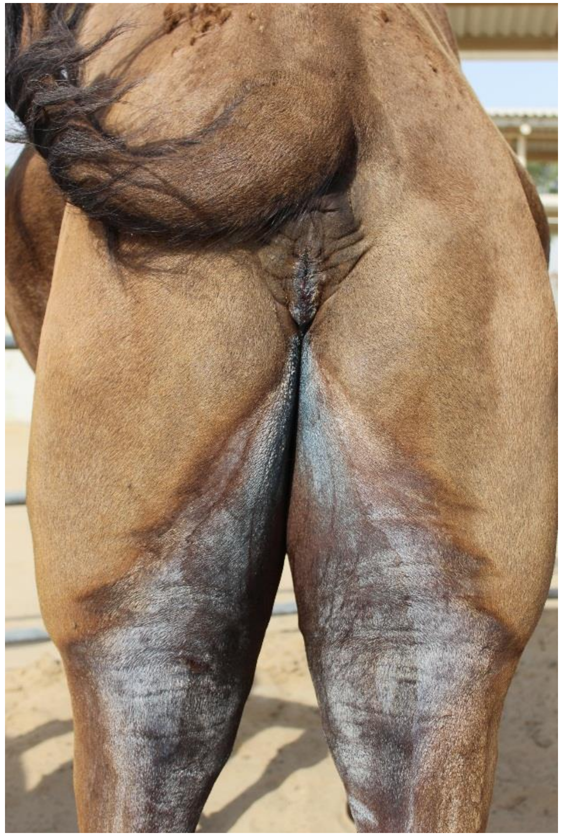


- Temperature of the exhaled air is **high during the day** and low during the night
- The cool venous blood from the nasal region drains via the cavernous sinus, **in the carotid rete** it cools the arterial blood flowing to the brain based on counter-current heat exchange (Ask-Upmark I935),
- Assuming 40 l/min of ventilation volume in a 500 kg camel, the amount of heat removed per minute is 3.42 kJ. This is sufficient to **cool about 410 ml blood by 2 ºC**.
- Exhalation of warm, saturated air in the daytime can permit **selective cooling of the brain** relative to body core temperature
- At night, when the surroundings are cool, this mechanism is not needed and the role of **water conservation** takes over.

Schmidt-Nielsen et al., 1981

Kidney function and urine excretion

- Anatomical features: small urinary bladder (<0.5 liter) and narrow urethra
- Unique way of urination
- Urine volume **low**: 1.5 - 5 liters
  - In dehydrated animals: 0.5 - 1.5 liters
  - Low GFR (0.5-1 ml/kg/min)
  - Low urine flow (2 ml/kg/h) compared to ruminants
- Concentration very **high**
  - osmolality 548 - 2,372 mosm/kg (mean 1466 mosm/kg)
  - In a sample 19.2 g/L Na, 3.8 g/L K and 34.4 g/L Cl
- Ability to drink **water with high** salt content
- **Urea recycling** under low protein diet
  - decrease in dietary protein (13.6 to 6.1 %) ➡ 86-92 % increase in urea recycling
  - urea transported to C1 (rumen) for bacterial amino-acid and protein synthesis



Schmidt-Nielsen, 1964; Yagil and Berlyne, 1978

Total daily water turnover of a dromedary camel

TABLE 1. ACCOUNT OF DAILY WATER INTAKE AND OUTPUT OF A CAMEL

Date		Daily Water Intake, % of B. Wt.				Daily Water Output, % of B. Wt.			
		Drinking	In food	Oxidation	Total	Feces	Urine	Evaporation	Total
5–12 Dec.	D	.85*	.14	.22	1.21	.36	.23	.62	1.21
27 Jan.–10 Feb.	H	1.31	.14	.22	1.67	.50	.30	.87	1.67
29 May–5 June	H	4.46	.05	.21	4.72	.38	.34	4.00	4.72
5–22 June	D	1.99*	.05	.21	2.25	.30	.52	1.43	2.25
22–27 June	H	4.59	.05	.22	4.86	.30	.37	4.19	4.86

Schmidt-Nielsen et al., 1956

Total daily water consumption of a lactating dromedary

- 622 kg average BW and 7.2 kg of average milk per day
- 6.22 x 4.9 liters of water + 6.5 liters of water in milk → estimated **37.0 liters**

→ measured **45.6 liters**

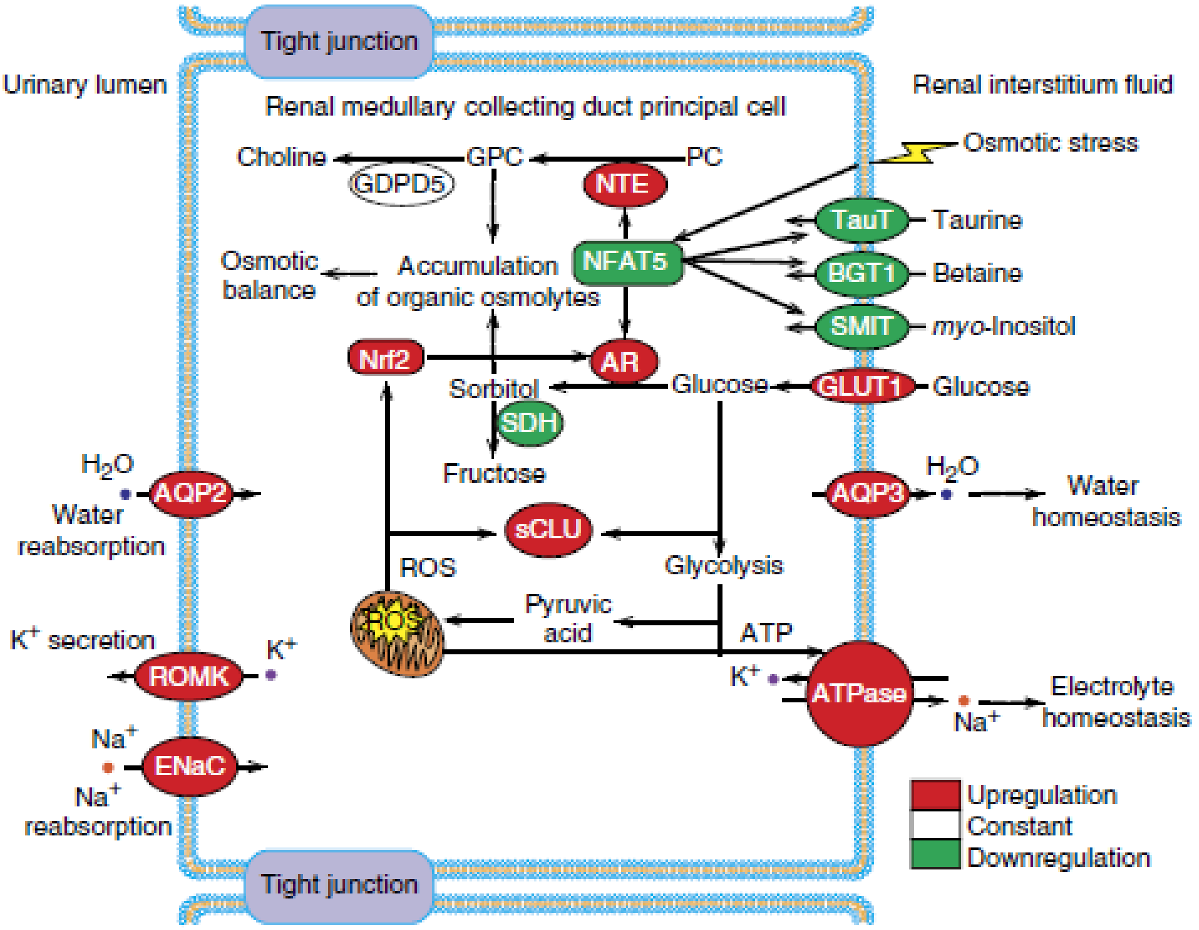
nature COMMUNICATIONS

ARTICLE

Received 6 Feb 2014 | Accepted 9 Sep 2014 | Published 21 Oct 2014

DOI: 10.1038/ncomms6188

Camelid genomes reveal evolution and adaptation to desert environments



Huiguang

Figure 4 | Schematic model of renal medullary osmosis and water reservation in the camel under water restriction. The shading of boxes indicates the upregulation (red), constant expression (white) or downregulation (green) of genes in the renal medulla of Bactrian camels during WR. The dashed lines indicate the ultimate functions or effects of the gene expression and the related product's activities.

Huiguang et al., 2014

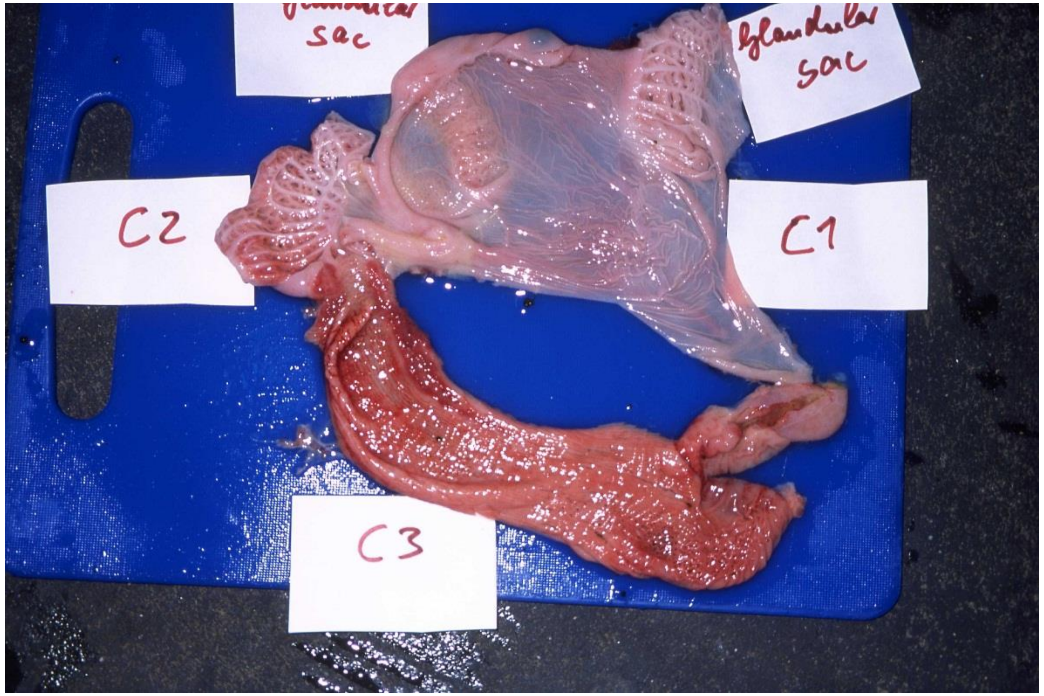
Tolerance to dehydration and recovery

- Exceptional tolerance to dehydration
  - in most species water loss up to **12-14 %** of BW in hot environment is fatal
  - 17 days without water in winter → 16.2 % loss in BW (36.5 kg)
  - 7 days without water in summer → **27.2 %** loss of BW and loss of appetite
- Distribution of water loss
  - interstitial water loss → 38 % (15.8 liters)
  - intracellular water loss → 24 % (32 liters)
  - plasma water loss → **8.8 %** (1.2 liters)
- Blood viscosity is low and rather constant during temperature changes
- High **drinking capacity** but no water storage
  - largest quantity at once 107 liters in 10 minutes
  - largest total quantity 186 liters in two portions
  - camels tolerate **blood hypo-osmolality** for long time (decrease by 12 mosm/kg for >30 hours) due to erythrocyte resistance

Schmidt-Nielsen, 1964; Benlamlih et al., 1992; Windberger et al., 2018

Digestive tract in camels

- Difference in morphology, histology and motility of the forestomach
- **3 compartments** (C1, C2 and C3)
- Dorsal part of C1 is stratified epithelium
- Ventral part made up by **glandular mucosa**
- C3 is long, intestine-like organ ends in hindstomach (H)
- During motility, fluids are pressed into glandular sac (GS) for potential absorption



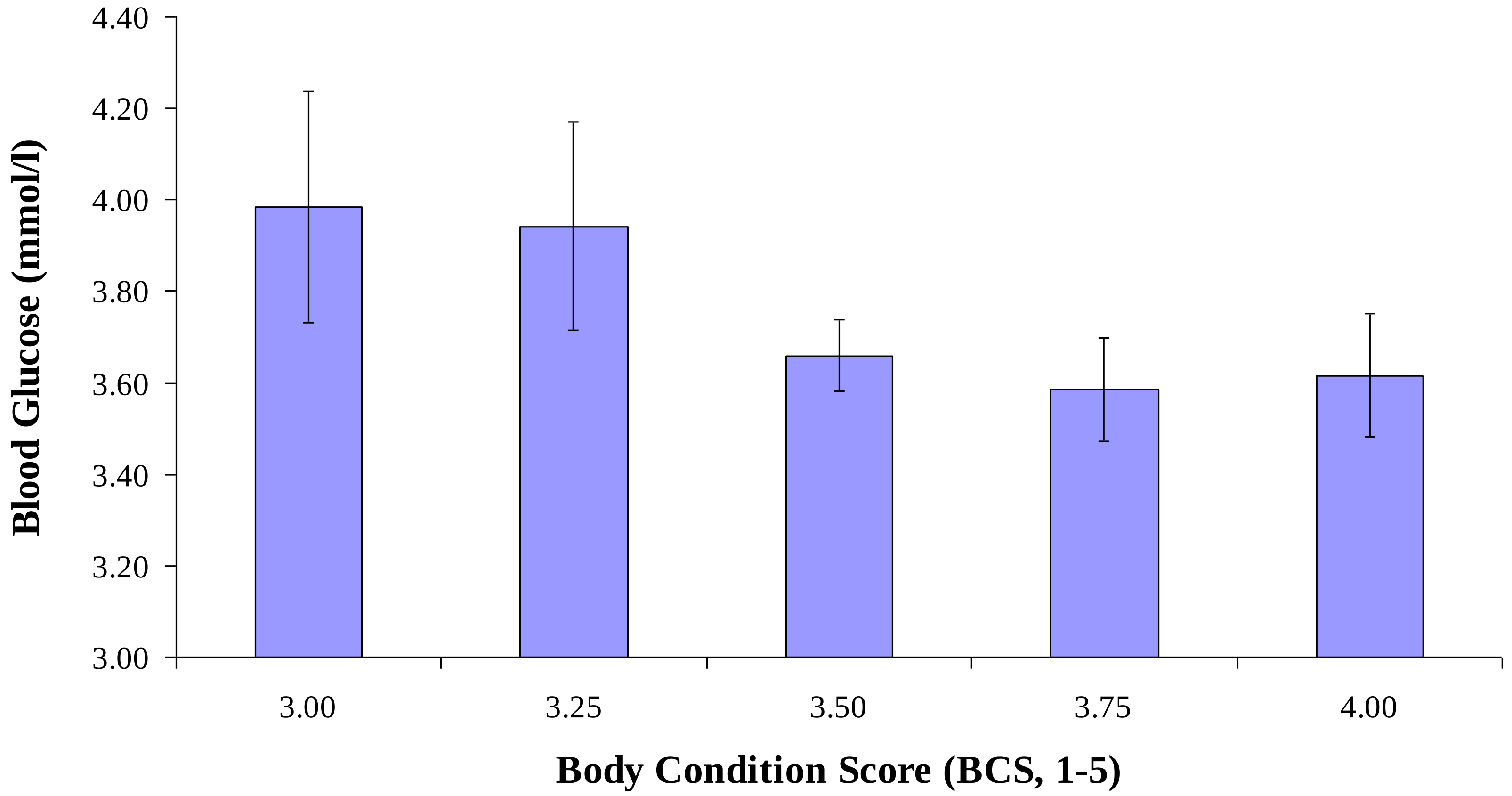
Camelids are ruminating but are not Ruminants

Ability to digest poor quality forages and high salt content plants (halophytes)
Urea recycling if feed protein content is low

Energy metabolism: myth and reality I.

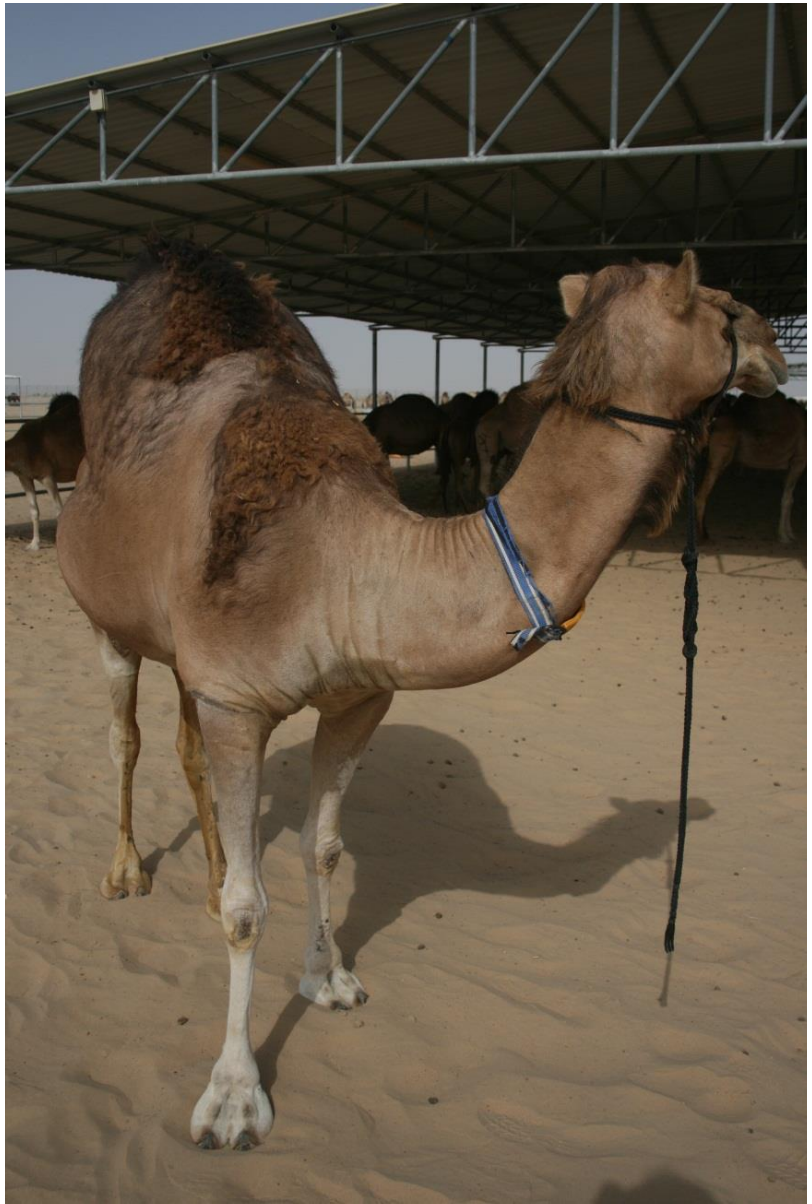
- **Efficient** energy conservation (adaptation) and **low basal** metabolism (DMI ≈1 %)
  - 500 kg camel on **4-5 kg** of poor hay or straw
- **Metabolic "history"**: more weight gain after underfeeding (Bengoumi et al., 2005)
- Blood **glucose is higher** in camels than in sheep and ponies
  - Camel >100-120 mg/ml or >5.6-6.7 mmol/l
  - Sheep 36-72 mg/ml or 2-4 mmol/l
- **Slow rate of glucose elimination**: poor insulin response or reduced tissue sensitivity (Elmahdi et al., 1997)
- **High incidence of diabetes** (type II, 21 %, > 140 mg/ml or 7.8 mmol/l) after high-calorie diet (Ali et al., 2006)
- **No correlation** between plasma leptin and body weight, BCS (Bengoumi et al., 2005)

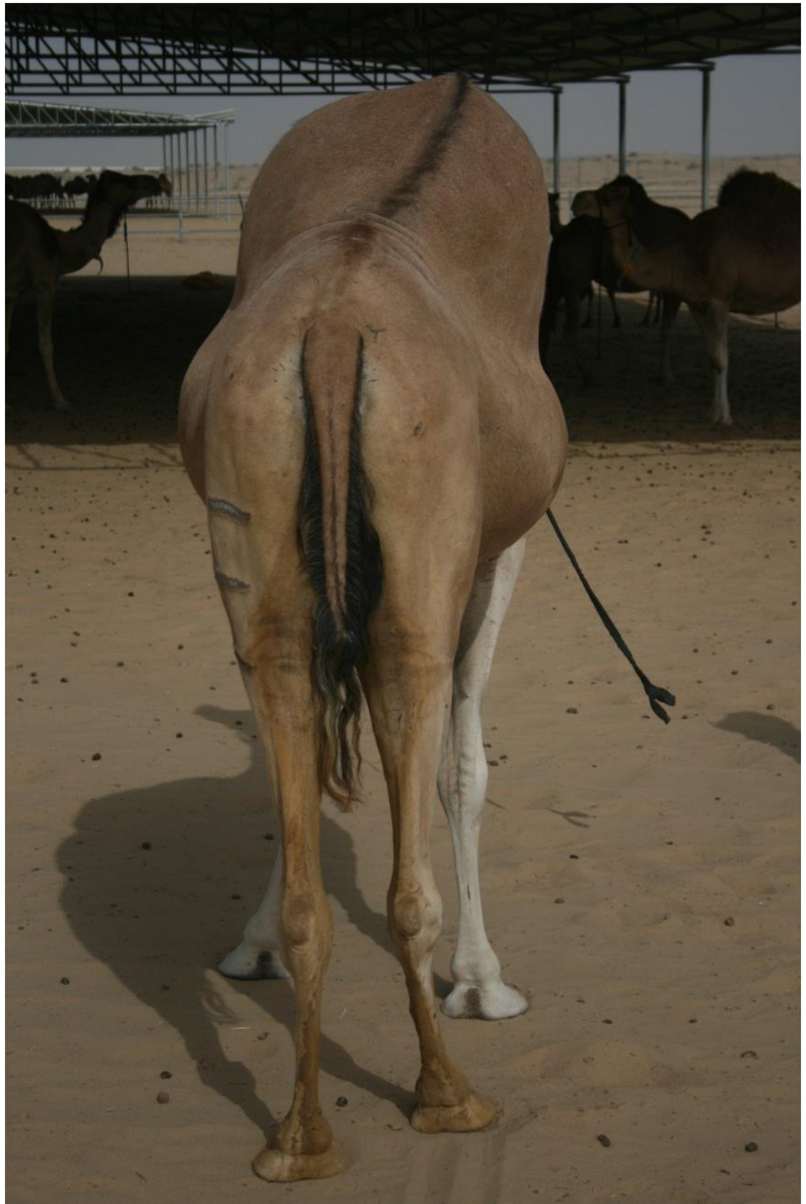
Blood glucose levels early morning in non-lactating dromedaries with different body condition



Blood Glucose ⇒ 3.85 ± 0.12 mmol/l or 69.4 ± 2.1 mg/ml (SEM)

Challenges under intensive management: obesity

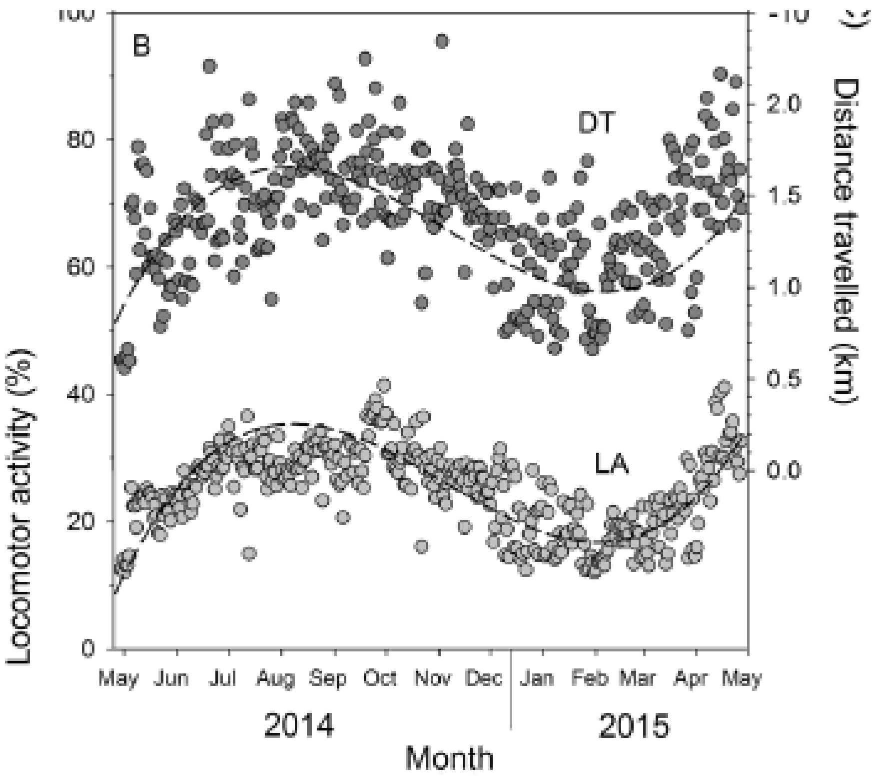


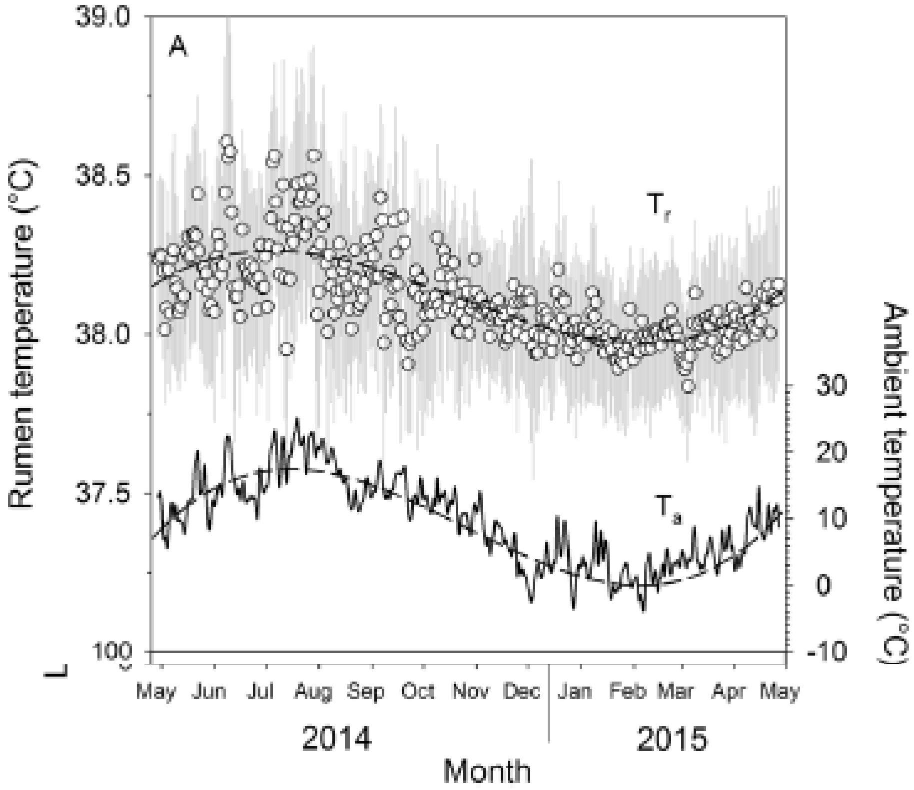


SCIENTIFIC REPORTS

Seasonal changes in energy expenditure, body temperature and activity patterns in llamas (*Lama glama*)

Alexander Riek[1], Lea Brinkmann[1], Matthias Gauly[2], Jurcevic Perica[3], Thomas Ruf[3], Walter Arnold[3], Catherine Hambly[4], John R. Speakman[4,5] & Martina Gerken[1]

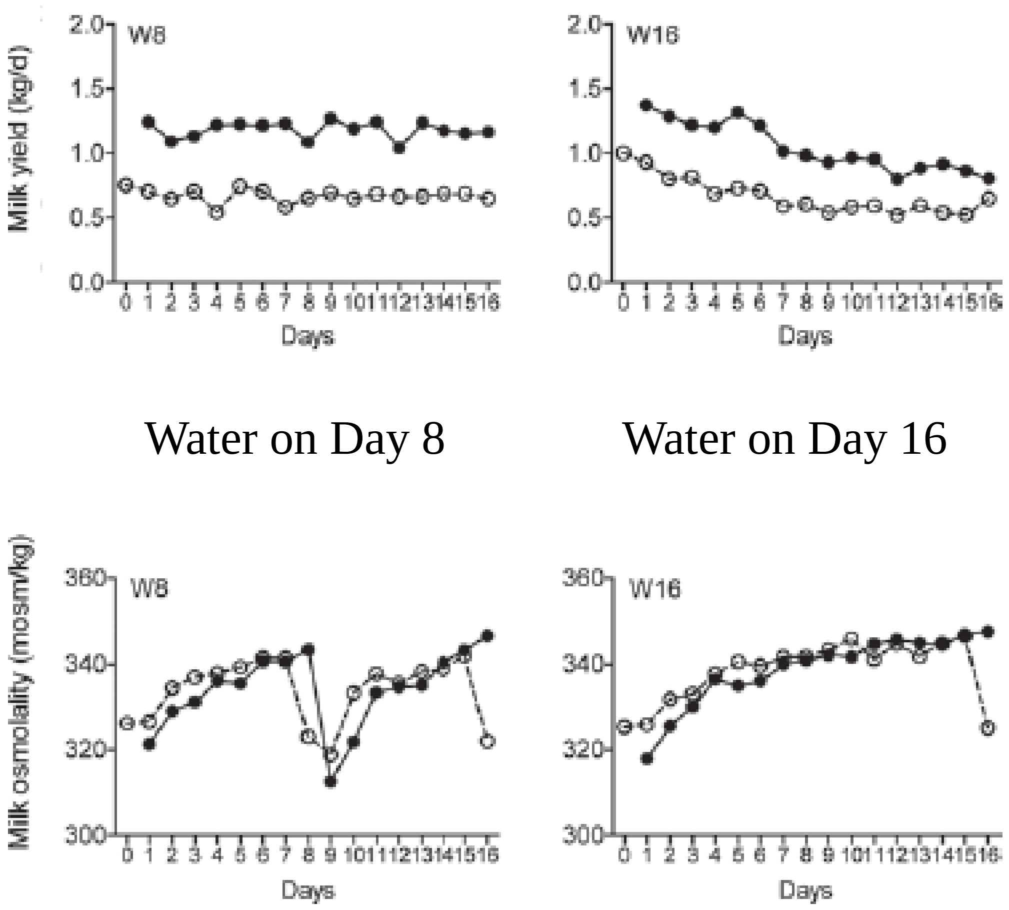




Riek et al., 2017

Milk production without water: myth and reality II.

- It was widely accepted that camels maintain milk production and **dilute milk** during water deprivation and dehydration (Yagil and Etzion, 1980)
- Milk quantity is constant for one week during water deprivation
- But, milk osmolality increases in parallel with plasma osmolality
- Camels **do not dilute milk when dehydrated** (Bekele et al., 2011)

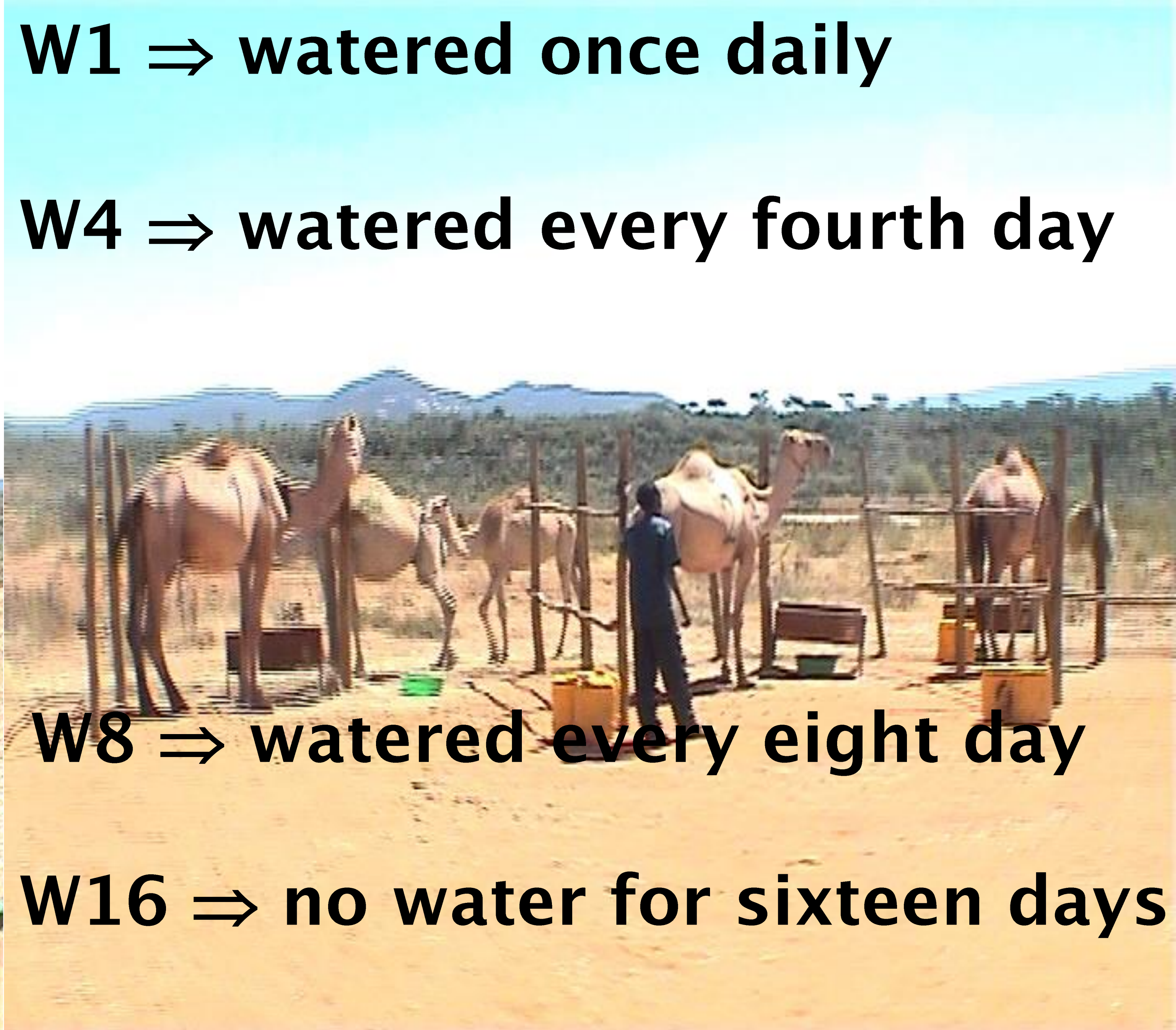


Water on Day 8

Water on Day 16

Bekele et al., 2011

Effects of different watering regimes on milk production and feeding behaviour in lactating camels in Errer valley



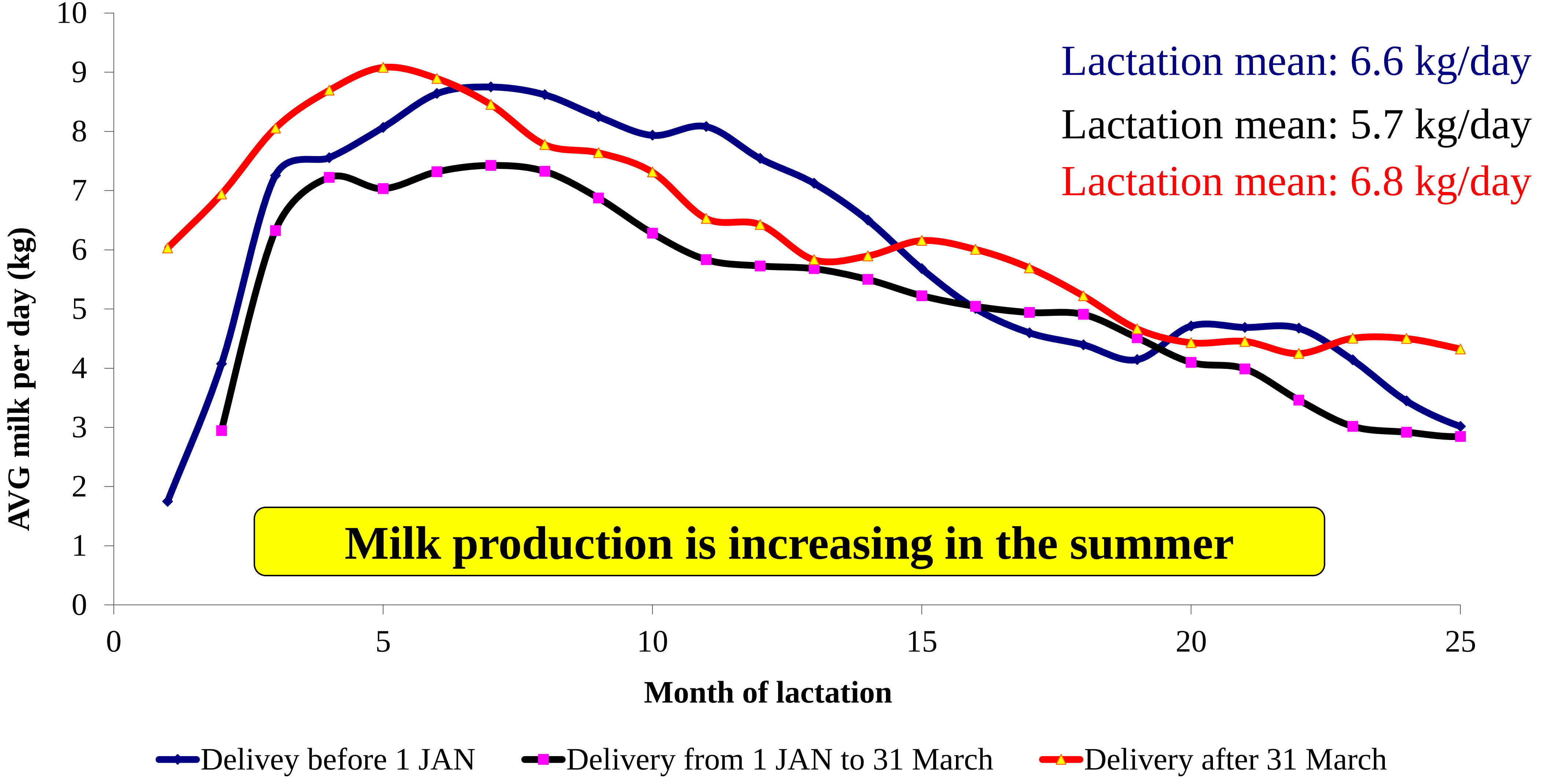
Bekele et al., 2011

Conclusion of the study

- Camels can feed and continue to produce milk during sixteen days without water.
- However, food intake and feeding time decreased when the dehydration period was prolonged.
- Camels do not increase milk volume
- Nor camels dilute their milk during water deprivation

Bekele et al., 2011

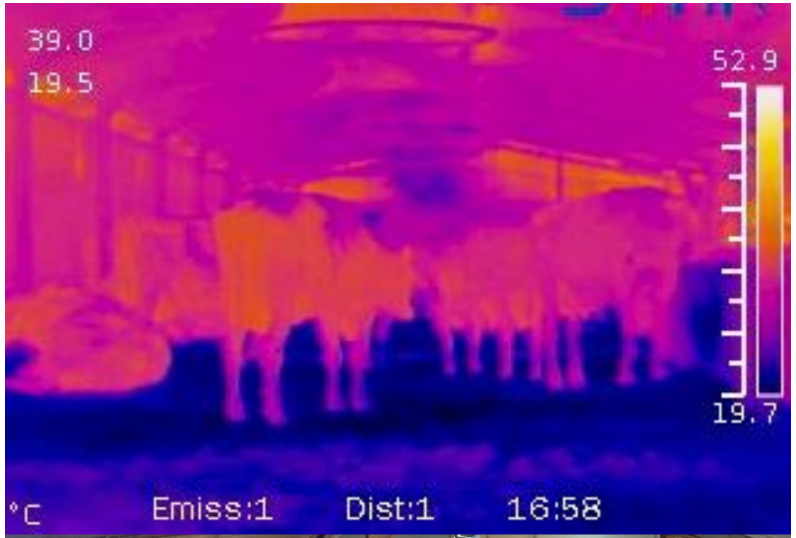
Sensitivity to heat stress ?
Milk production in the summer



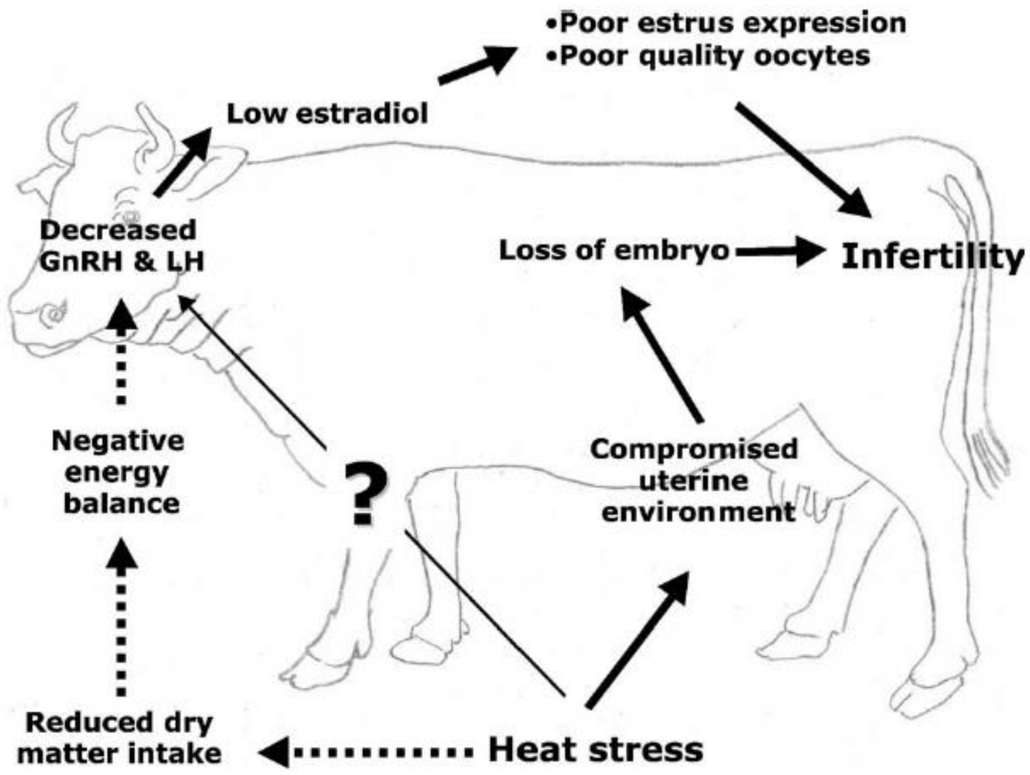
Comparison of a dairy camel with a dairy cattle

	Camel	Cow
Body weight (kg)	620	650
Milk production (kg)	7.2	≈40
Dry matter intake (kg)	13.3	≈25
Drinking water (l)	45	≈250
Water for cooling (l)	0	≈500
Total water use (l)	≈60	≈1000

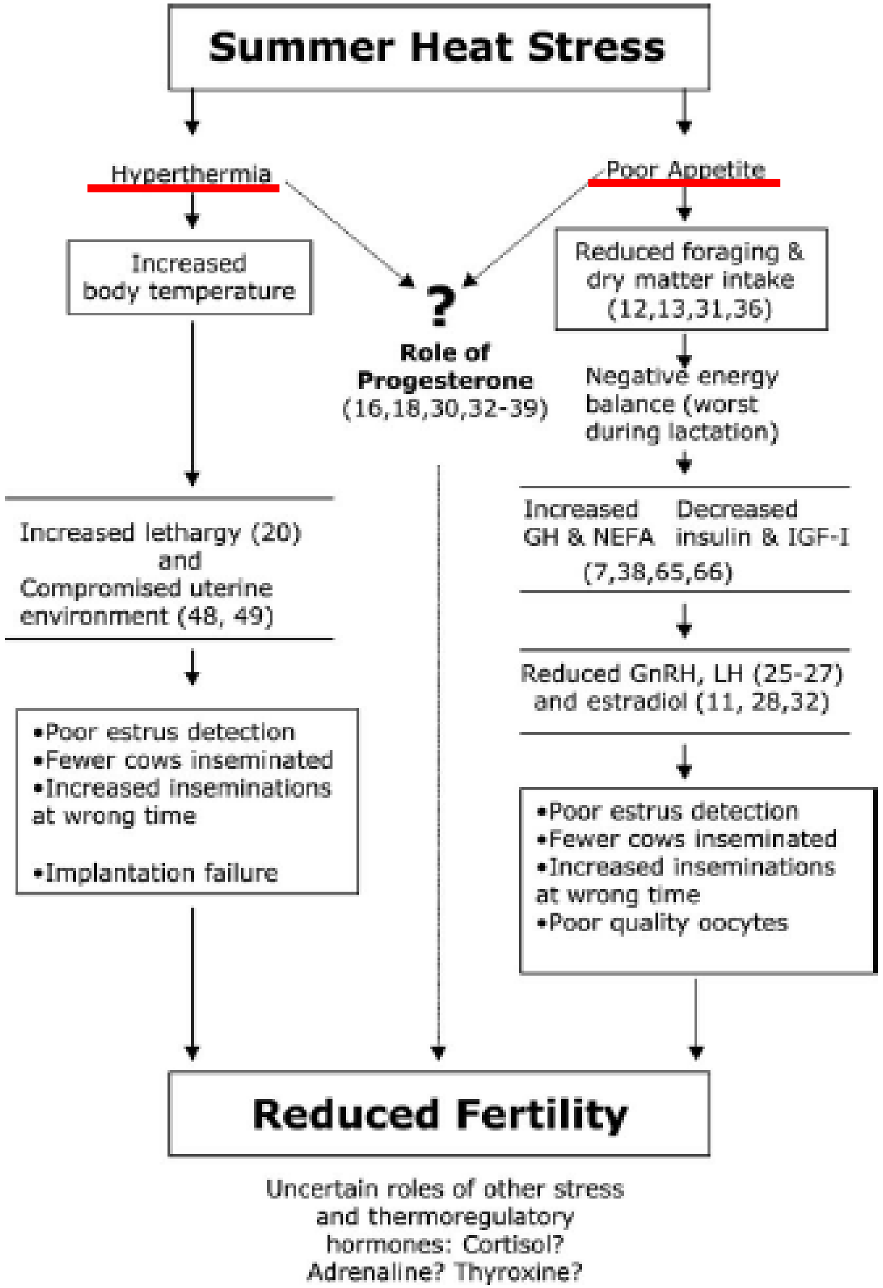
Daily water requirement (<60 liter) is a fraction of that of a HF cow (>1000 liter)



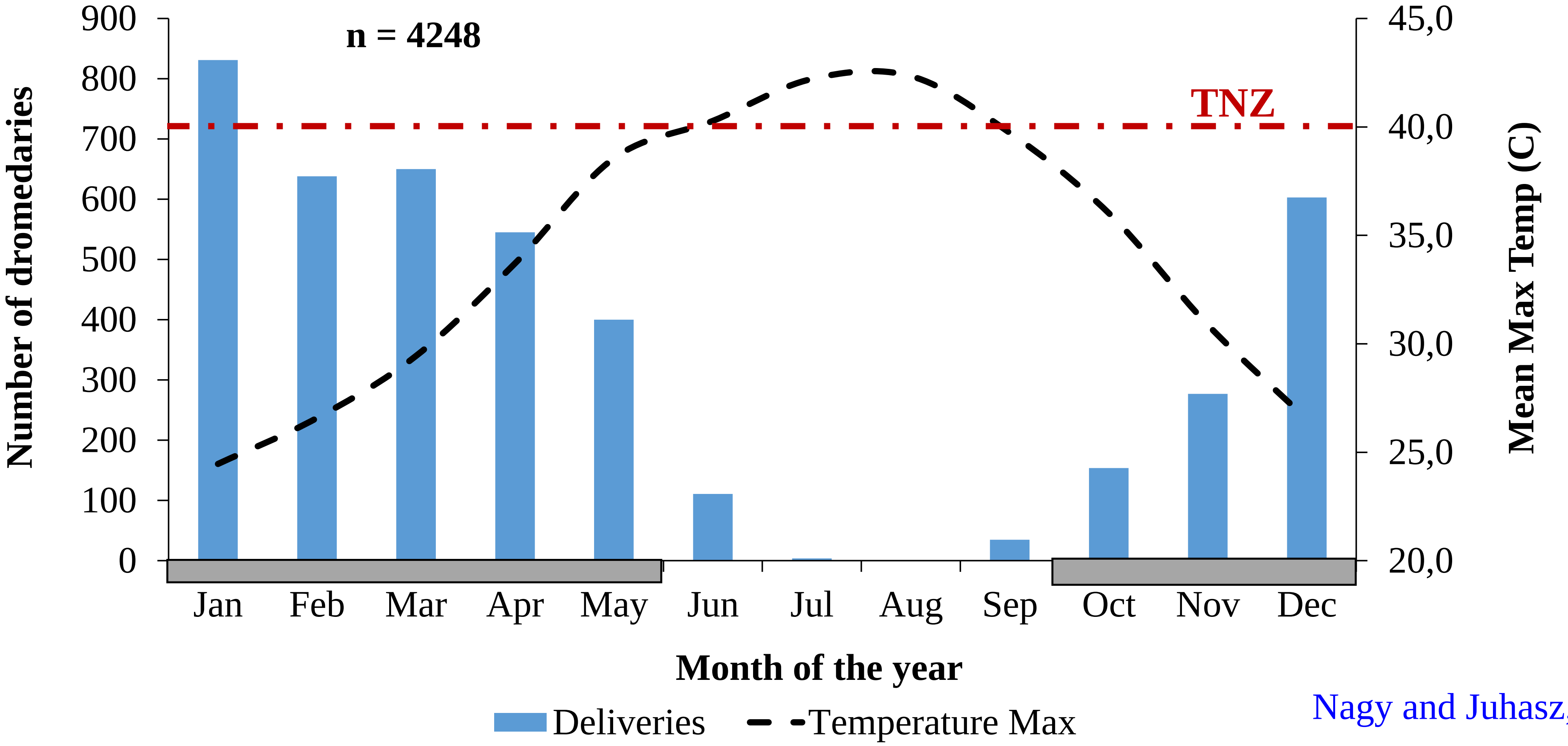
Effect of heat stress on reproduction in the dairy cow



De Rensis and Scaramuzzi, 2003



Does temperature influence reproduction in female dromedaries ?

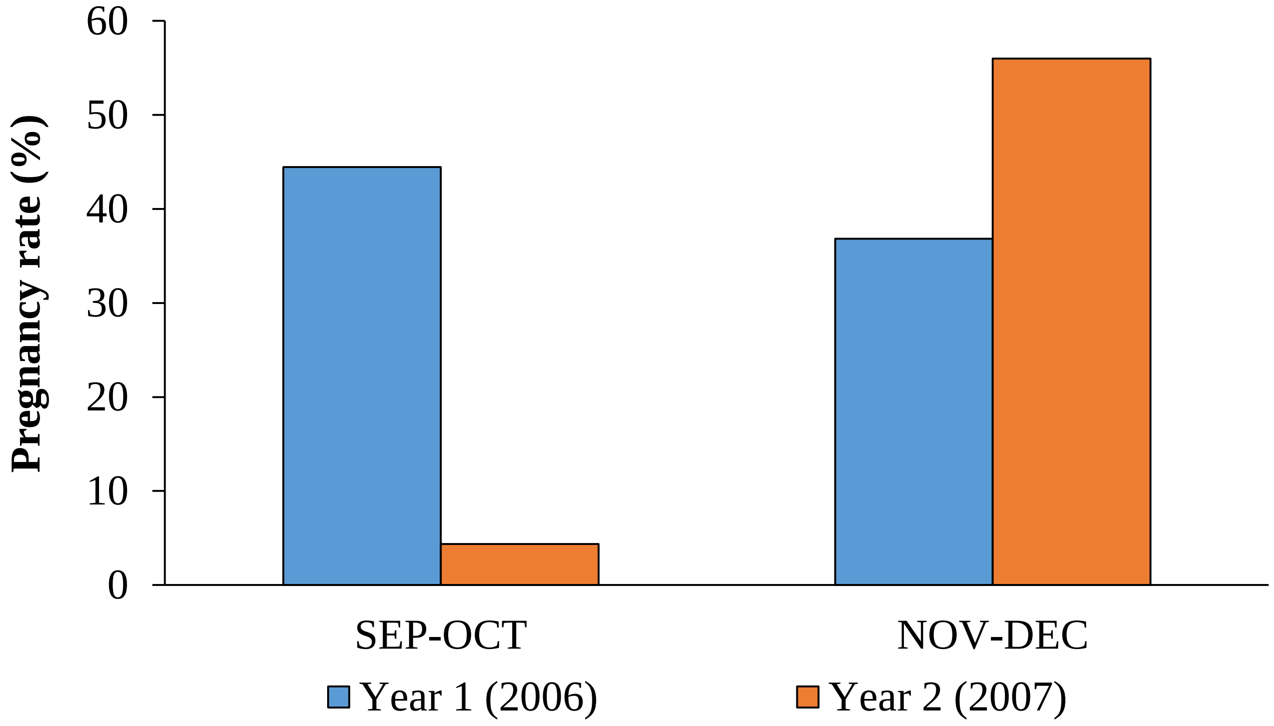


Nagy and Juhasz, 2019

Seasonal breeding is more likely related to photoperiodic changes and male libido

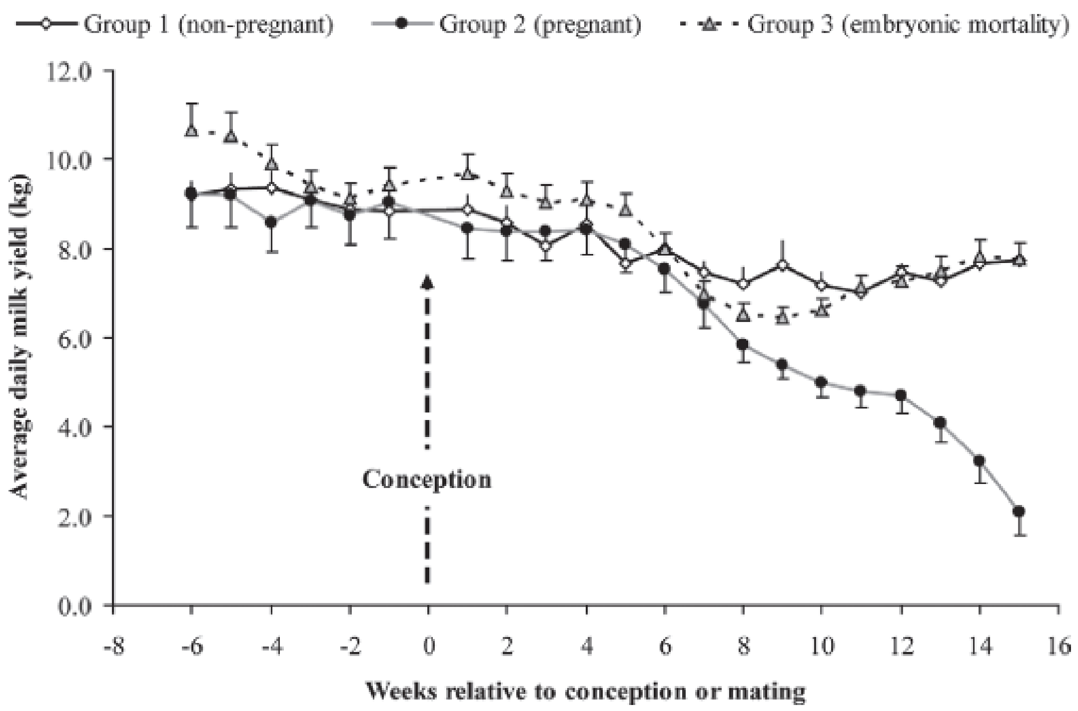
Effect of temperature on male fertility

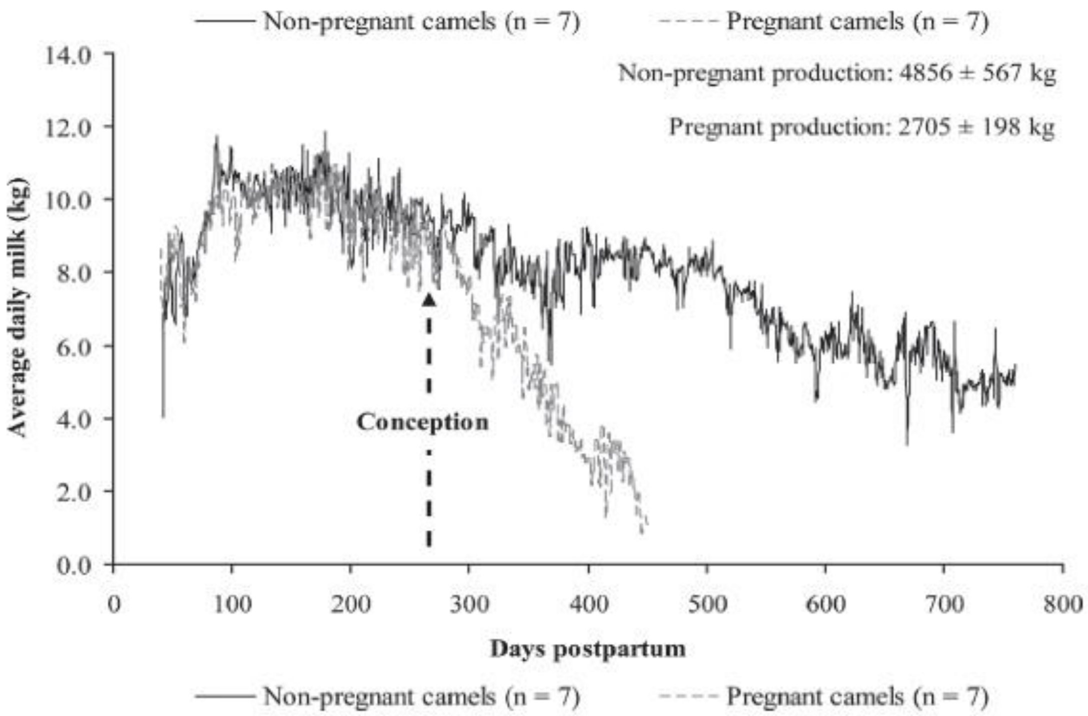
Pregnancy rate of one male in two seasons due to different management



Sand temperature in 2007 > 50 to 60 ºC

Interaction between pregnancy and lactation





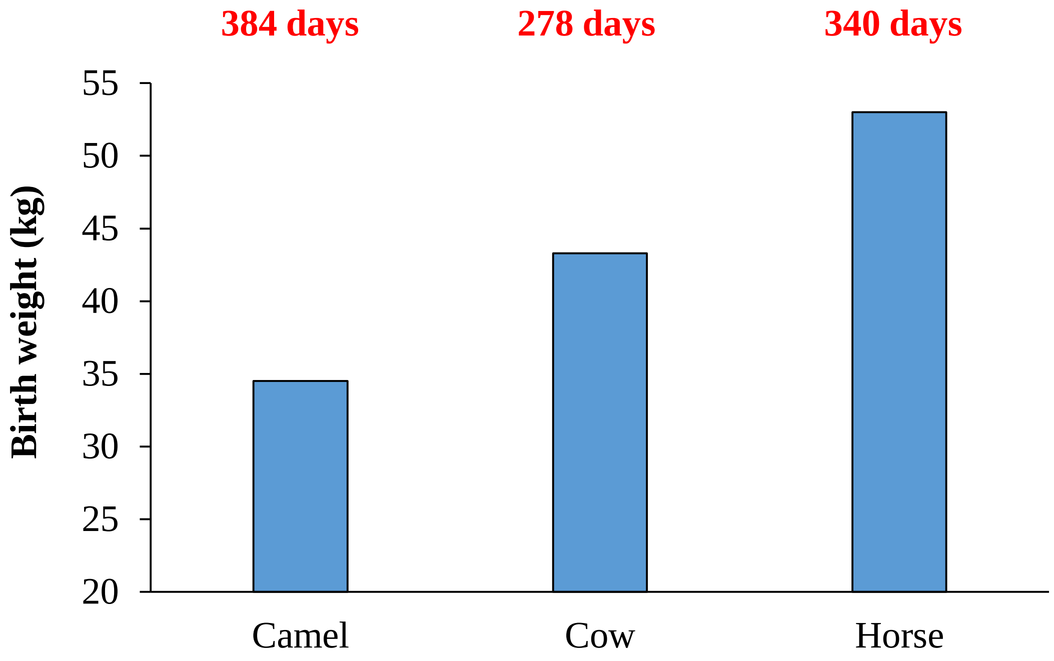
breakpoint after 28 ±7 days, but milk production resumed after embryonic mortality

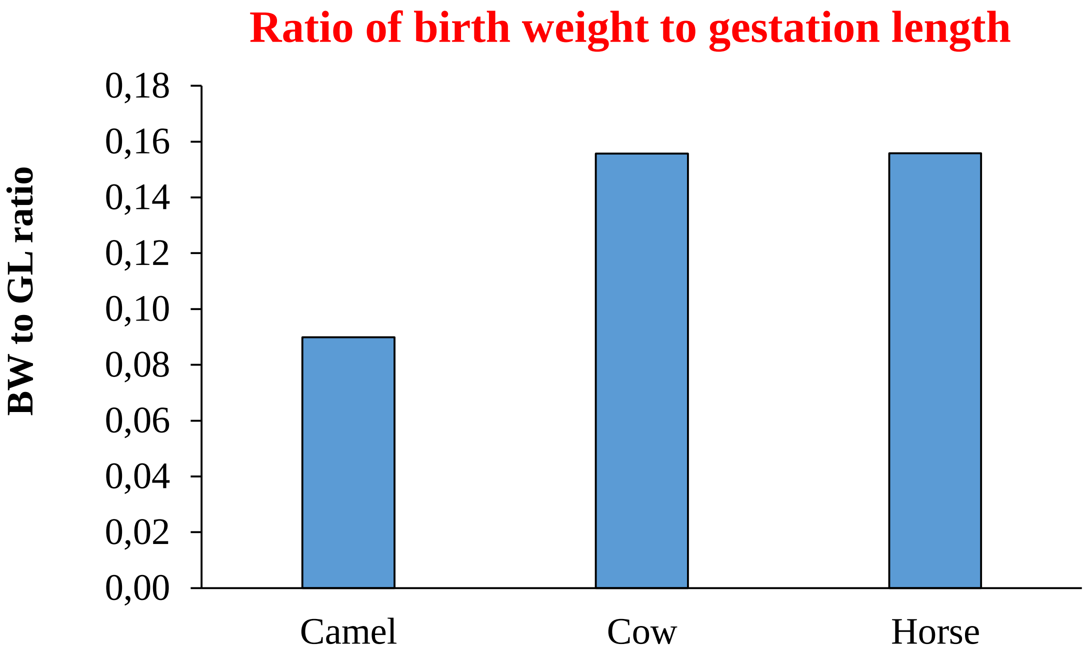
30- 45 % reduction in total production and DIM

Signalling pathway of mammary gland regression may include P4, E2, prolactin and IGF-I

Nagy et al., 2015

Fetal development and birth weight





Dromedary calves reach full maturity after longer gestation, but at much lower weight compared to equine and bovine foetuses

This is part of the mechanisms how the species adapted to limited feed sources in desert environment

Nagy and Juhasz, 2019

Conclusions

- Dromedary camel population is growing
- Upper limit of the thermo-neutral zone is app. 40 ºC
- Camels do not store extra water in their body
- Minimize water losses with various mechanisms
- Have high tolerance to dehydration and fast recovery
- Able to utilise marginal feed sources (high salt content) efficiently
- Are not sensitive to "heat stress" under normal watering conditions
- Synchronize seasonal reproduction around ambient temperature and feed supply
- Prioritize energy and nutrients towards gestation rather than towards lactation
- Gestation physiology and fetal development adapted to limited food sources

Perfect species for production in arid, semi-arid climate


Thank you for your attention!
although adapted to desert,
we still prefer the shade…
Best wishes to
the EAAP Camelid WG

Hope to see you at the next scientific meeting in Bologna, Italy

The ICAR 2020 Satellite Meeting on Camelid Reproduction

3rd – 5th July