Digestibility of starch as a risk factor for life-style diseases

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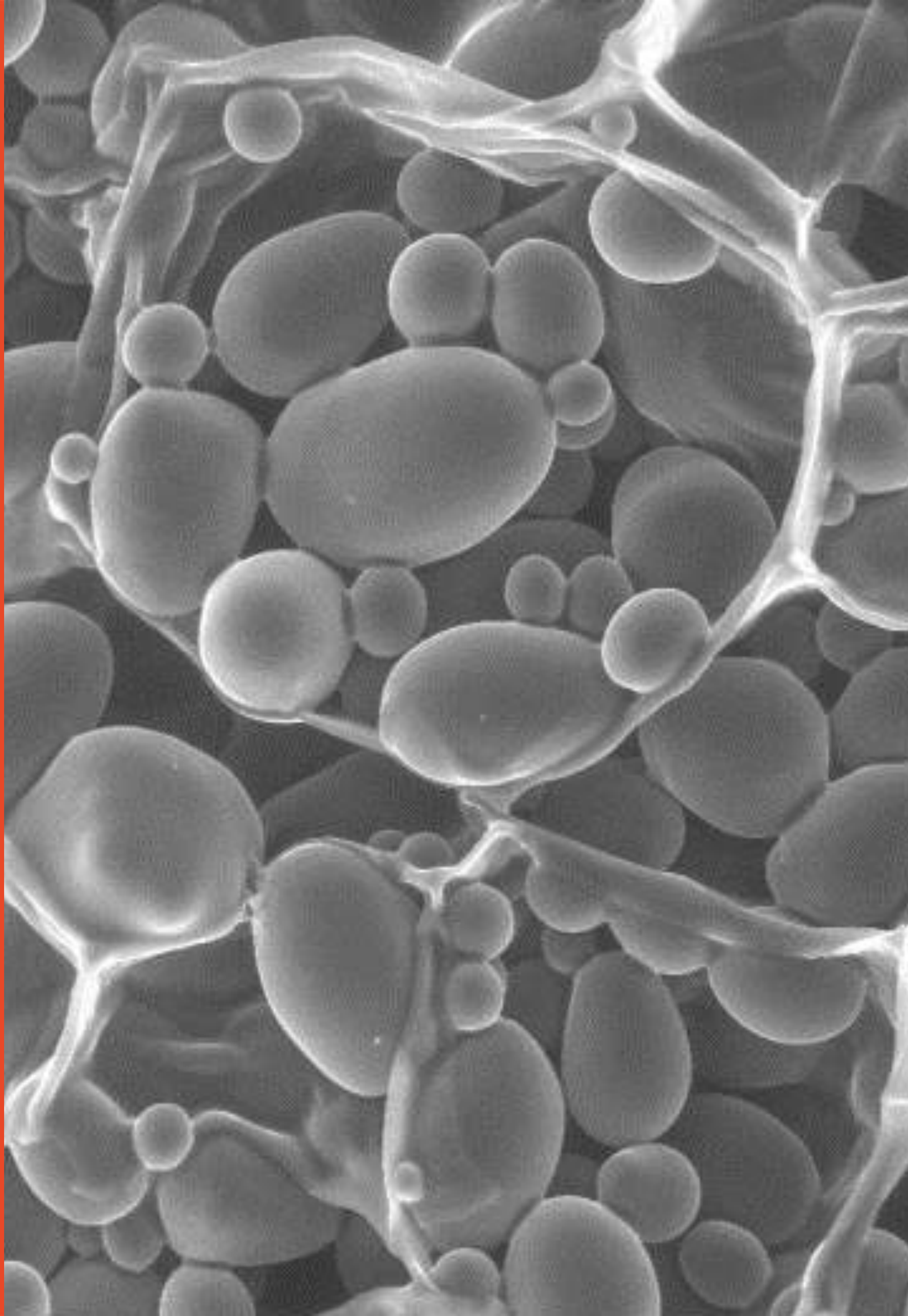
28 Sep 2016



Grand challenges

- Food
- Resources
- Climate

- Agriculture as an instrument of public health
  - reduce illnesses due to hunger, nutrient deficiencies, over consumption
    - in 2014, >600 million obese adults, >400 million with T2D
    - increased risk of cardiovascular disease, inflammatory diseases, cancers, cognitive decline, …
  - understand and improve functionality of foods and ingredients
    - modified carbohydrates for glycemic control, prebiotics
    - modified oils with better fatty acid profile, increase omega oils
    - increase bioavailability of micronutrients
    - nutraceuticals

Starch

- **Macro-nutrient in many foods**

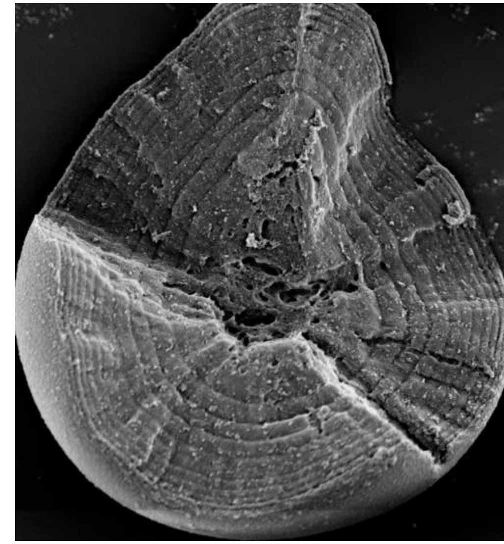
- **Major industrial product**
  - **60+ million t/yr extracted from wheat, corn, potato, rice, cassava, specialty sources**
  - **60% used in foods**
  - **40% for non-food uses**

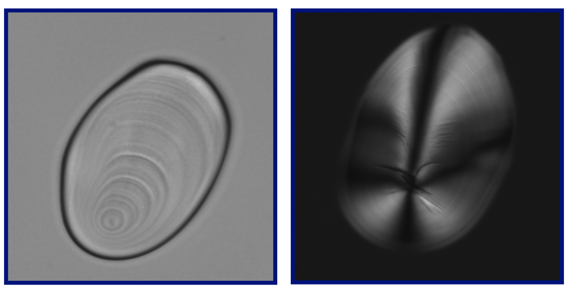
- **Occurs in plants as semi-crystalline granules**
  - **crystallinity ranges from 15% (high AM starches) to 45% (waxy starches)**

- **Variability of granules between and within species**
  - **size and shape, degree of crystallinity**
  - **organization of starch molecules within granules**
  - **potential for specialty applications but unpredictability of functional performance**

Molecular organization inside starch granules is complex

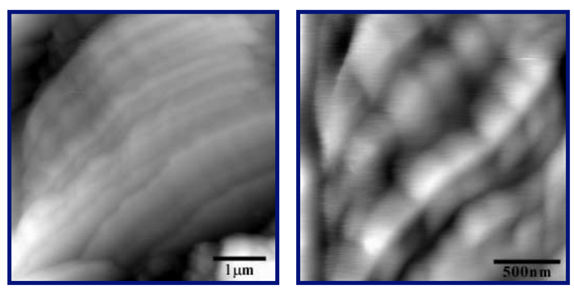
- **Limited understanding of how amylose (lightly branched) and amylopectin (highly branched) are arranged into crystalline and amorphous growth rings**





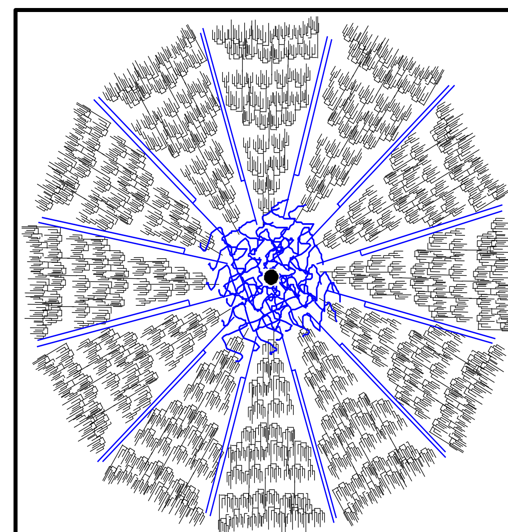
Light microscopy of potato starch

Ek et al. 2014. Brit J Nutr 111, 699-705
Ek et al. 2014. Food Funct 5, 2509-2515



AFM of rice starch

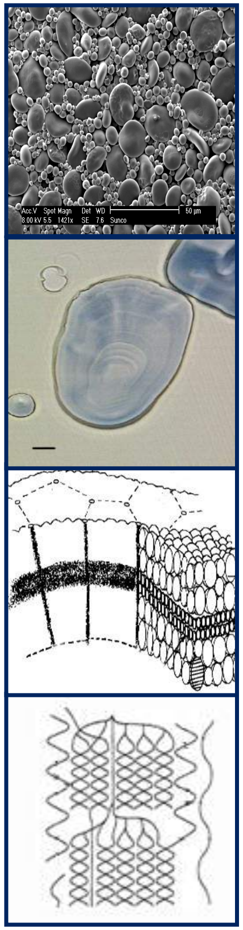
Dang and Copeland 2004. JSFA 84, 707-713
Dang and Copeland 2006. J Microscopy 224, 181-186



Wang et al. 2012. Carbohydrate Polymers 87, 1941-1949
Wang and Copeland 2012. Food Chemistry 135, 1635-1642

Structure determines function

µm



nm

Structure

- Macro (1-100 µm)
  - granules
- Micro (0.1-0.4 µm)
  - growth rings, crystalline and amorphous lamellae
- Nano (10-100 nm)
  - organization of AM & AP
  - AP branching pattern

- Physicochemical properties

Function

- Water absorption
- Swelling
- Viscosity
- Pasting
- Gelatinisation
- Retrogradation
- Gel properties
- Digestibility

- Collective properties

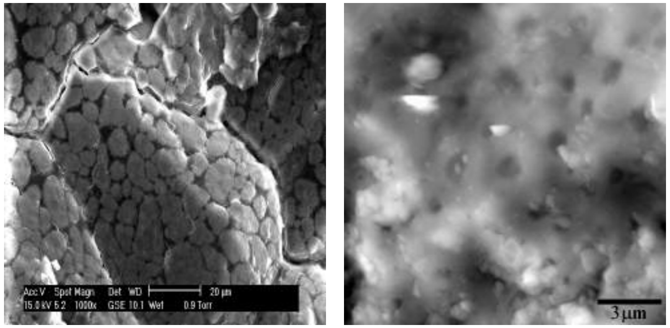
Structure is determined by biosynthesis

- multiple genes and enzyme forms
- developmental and environmental influences during growth

Difficult to assess contribution of specific properties to functionality of the whole

Cooking causes starch to gelatinize

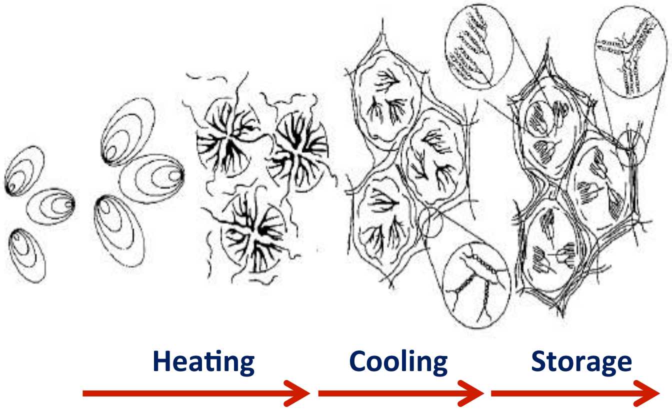
- Heat, moisture and shear disrupt granules irreversibly
  - granules absorb water and swell
  - H bonds break
  - AP crystallites melt, AM leaches out
- On cooling, dispersed starch molecules retrograde
  - aggregate into a new semi-ordered state
  - disrupted AP clusters entrapped in an AM matrix
  - min to hr for AM, hr to days for AP



Native and parboiled rice

Dang and Copeland L 2004 JSFA 84, 707-713

- Gelatinization and retrogradation
  - control most functional properties of starch in foods
    - digestibility, texture, water absorption, shelf life,
    - extent depends on type of starch, temperature, moisture, shear, rate and duration of heating and cooling, composition of mixture, …



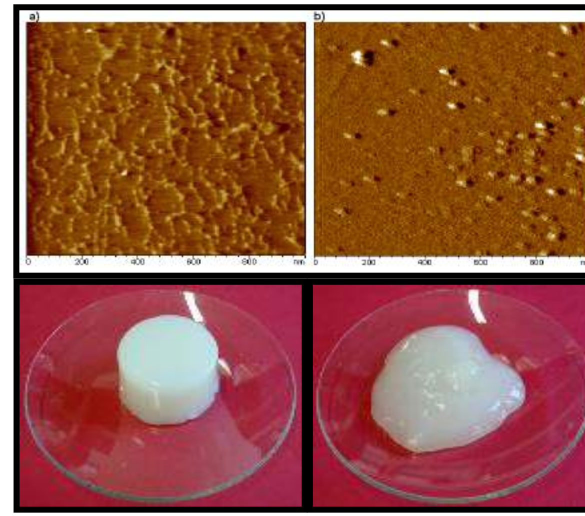
Goesaert et al. 2005

- Most processed foods contain a mixture of intact and partially disrupted granules, retrograded AM and AP

Wang et al., 2015. Comp Rev Food Sci Safety 14, 568-585

Starch gels

- Retrograded starch forms gels if concentration ≥ 4%
- Present in many cooked and cooled foods
- Affects digestibility
- Non-waxy starch gels are firm
  - strengthened by AM network
- Waxy starch gels and starch-lipid gels are soft
  - no AM network



Normal starch   Waxy starch

Starch   Starch + Monopalmitin   Starch + Tripalmitin

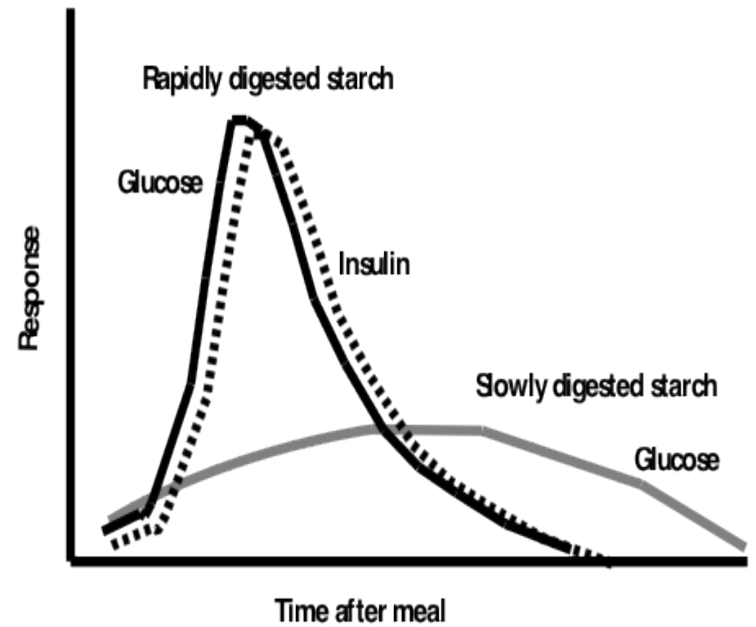
Tang and Copeland 2007. Carbohydr Poly 70, 1-7

Starch contributes 50-70% of dietary energy

- **Starch digestibility is linked to risk factors for disease**
- **Rapidly digested starch (highly-processed foods)**
  - **poor glycemic and insulin control**
- **Slowly digested starch (less-processed foods)**
  - **moderated glycemic and insulin responses**
- **Resistant starch (raw starch, cooked and cooled foods)**
  - **not digested in upper gut**
  - **prebiotic, no glycemic effect**
- **Slowly digested starch and resistant starch associated with health benefits**

- **Glucose released in the ileum triggers beneficial hormonal responses (ileal brake)**

- **Rapidly and slowly digested starch and resistant starch are kinetic phases of starch hydrolysis, not defined chemical entities**

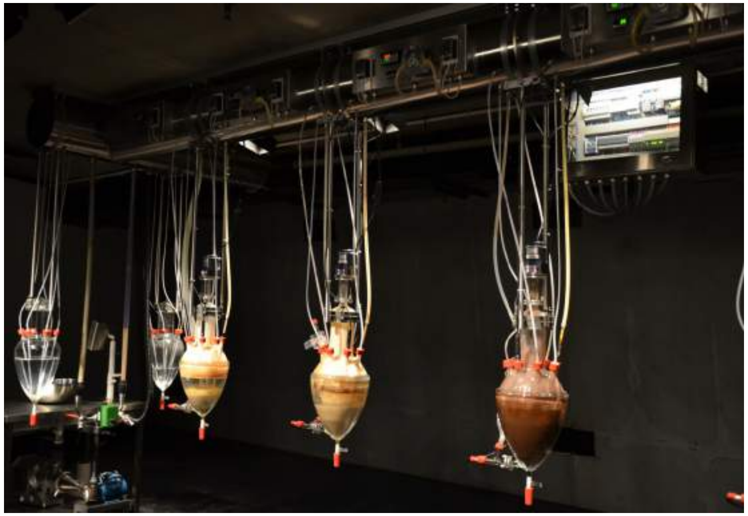


Glycemic effect of foods

- Caloric value of foods is an over-simplification
  - need to consider digestibility (bioavailability)
  - quality of calories

- Glycemic carbohydrates release glucose
  - starch, sucrose

- Glycemic Index indicates blood glucose-raising potential of a food
  - *in vivo* test of digestion, glucose absorption and clearance from bloodstream
  - low GI: <55 medium GI: 56-69 high GI: > 70
  - costly, slow, not always convenient, statistics
- *In vitro* testing methods are used as proxies
  - simple → complex
  - measure starch breakdown only
  - useful for high throughput and comparative studies
  - can be standardized



MONA, Hobart

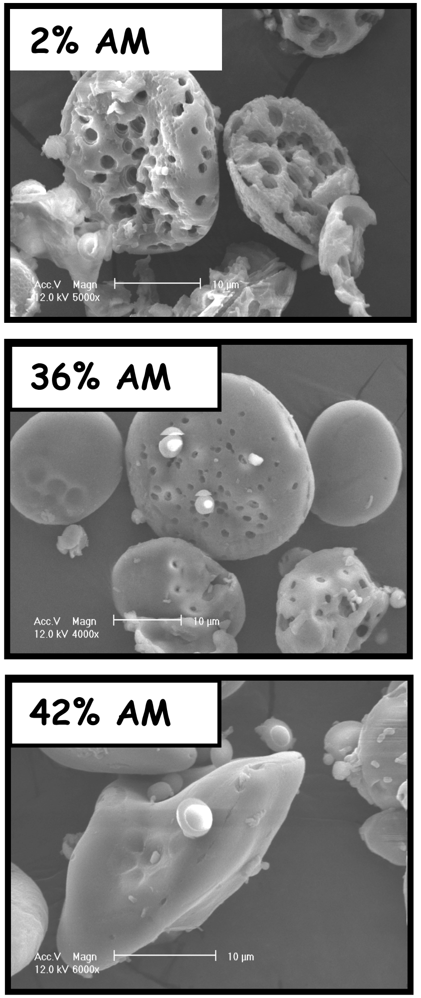
NutraScan, Next Instruments

Enzyme hydrolysis of of starch

Access of enzymes to the substrate is the rate limiting step
- form of starch (raw, encapsulated, structure, gelatinized/retrograded, complexes, …)

Raw starch (feeds and fermentations, uncooked foods)
- hydrolysis is slow
- affected by varietal differences, amylose content
- rate determined by surface effects

Cooked starch (processed foods)
- hydrolysis much more rapid than raw starch
- no differences between freshly-gelatinised starches
- influenced by extent of cooking and cooling



Wheat starch granules after 2 h with α-amylase

Blazek and Copeland 2010. J Cer Sci 51, 265-270; Blazek J and Copeland L 2010. J Cer Sci 52, 295-302; Wang and Copeland 2013. Food Funct 4, 1564-1580

Genotype x environment effects on amylolysis of starch

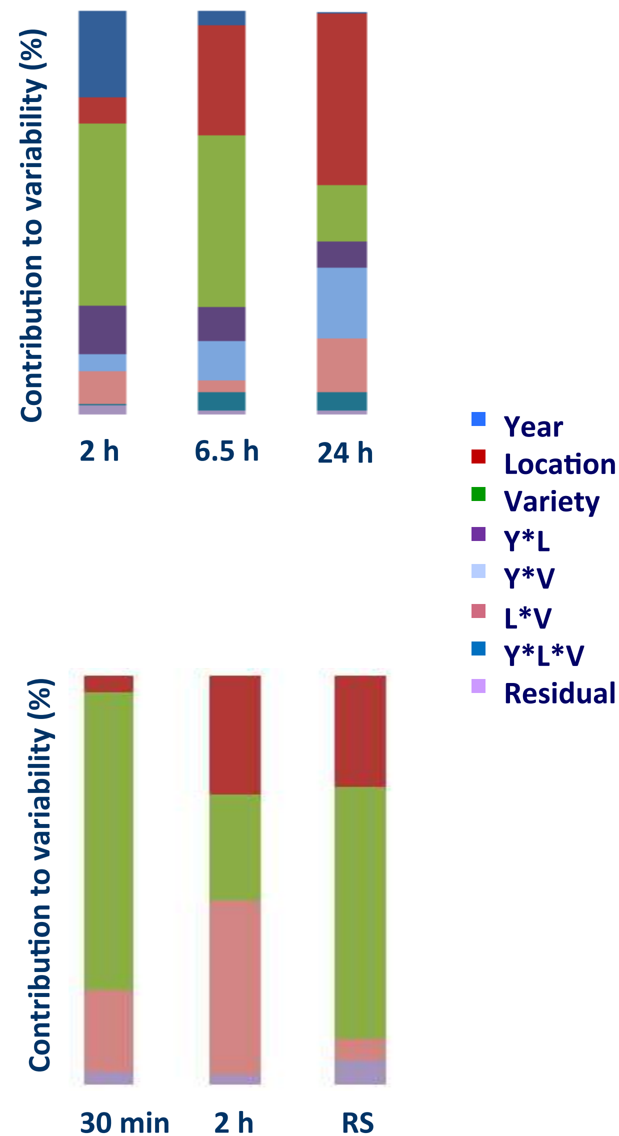
Native starch

- Genotype accounts for most of variance initially, but environmental factors become increasingly important
- Simple first order kinetics

Cooked starch

- Conditions for gelatinization and retrogradation accounted for much of the variance in digestibility
- For a specific set of conditions, genotype contributed about 60-70% of the variance in rapidly digested and resistant starch
- Complex kinetics – heterogeneity of substrate

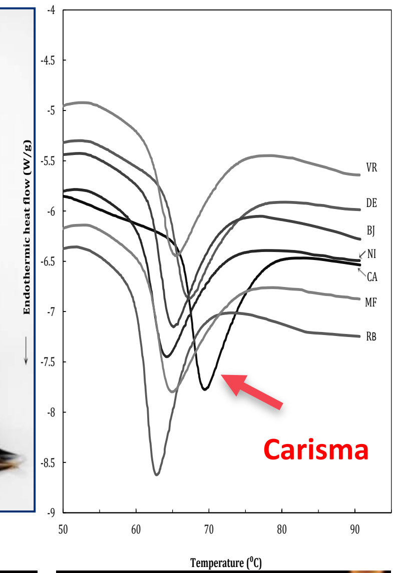
Heritability of susceptibility to amylolysis

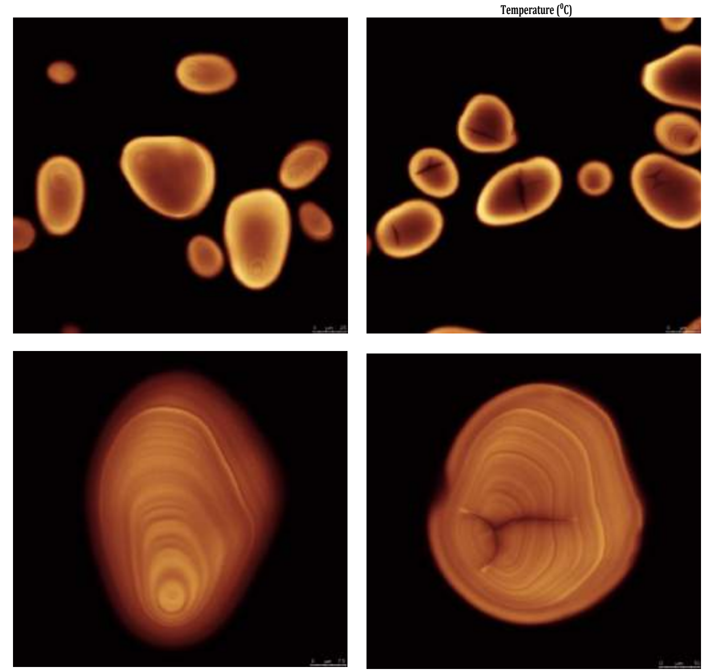


Nhan MT and Copeland L 2015. IJFST 50, 1945-1952; Nhan MT and Copeland L submitted

Genotypes for slow digestibility

- Carisma™ is a low GI potato
- Selected for firm cooking quality, size, agronomy
- Carisma starch does not gelatinize as readily as other potato starches
- Cell wall thickness may also be a factor





Carisma Russet Burbank

Ek 2014. British Journal of Nutrition. 111, 699-705.
Ek 2014. Food and Function 5, 2509-2515.

Carbohydrates are the main food for gut microbiota

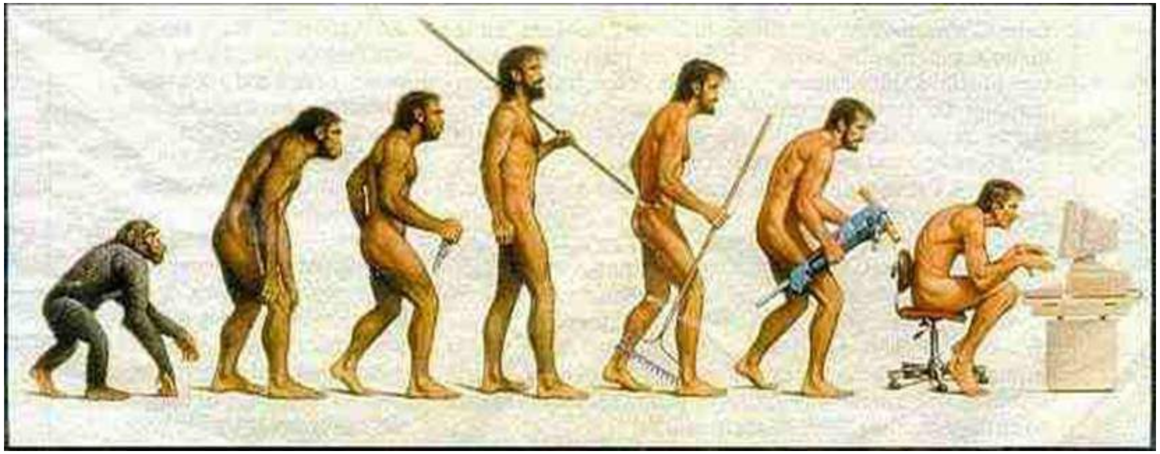
- Carbohydrates that escape digestion in the upper gut provide essential dietary fibre, prebiotics
  - mostly resistant starch, non starch polysaccharides

- Gut microbiota strongly influence physiology
  - impact of diet on host metabolism
  - predisposition and resilience to disease
  - inflammatory and autoimmune conditions
  - cognitive abilities

- Complexity of species, taxonomic and functional diversity
  - influenced by diet, lifestyle, hygiene
  - resilience varies between individuals
  - changes in gut microbiota are associated with human disease – cause or effect?

MICHELLE POSSUM NUNGUARRAYI
Indigenous Australian art
www.aboriginal-art-australia.com

Role of nutrition in human evolution



- What is a healthy diet?
- Is our physiology adapted to the diet we evolved with?
- How and why did humans develop such large brains?

A new hypothesis

- Starchy plant foods in the Paleolithic were essential for the evolution of modern humans
- Essential for the increased metabolic demands of a growing brain and to support successful reproduction and increased aerobic capacity

Hardy K, Brand-Miller J, Browne KD, Thomas MG, Copeland L. 2015.
The importance of dietary carbohydrate in human evolution. Quarterly Review of Biology 90, 251-268.

Early hominins

Brain

- increase in size began around 2 million years ago, accelerated from about 800,000 years ago
  - increased from 400 cc to 1800 cc
- required an increased supply of glucose

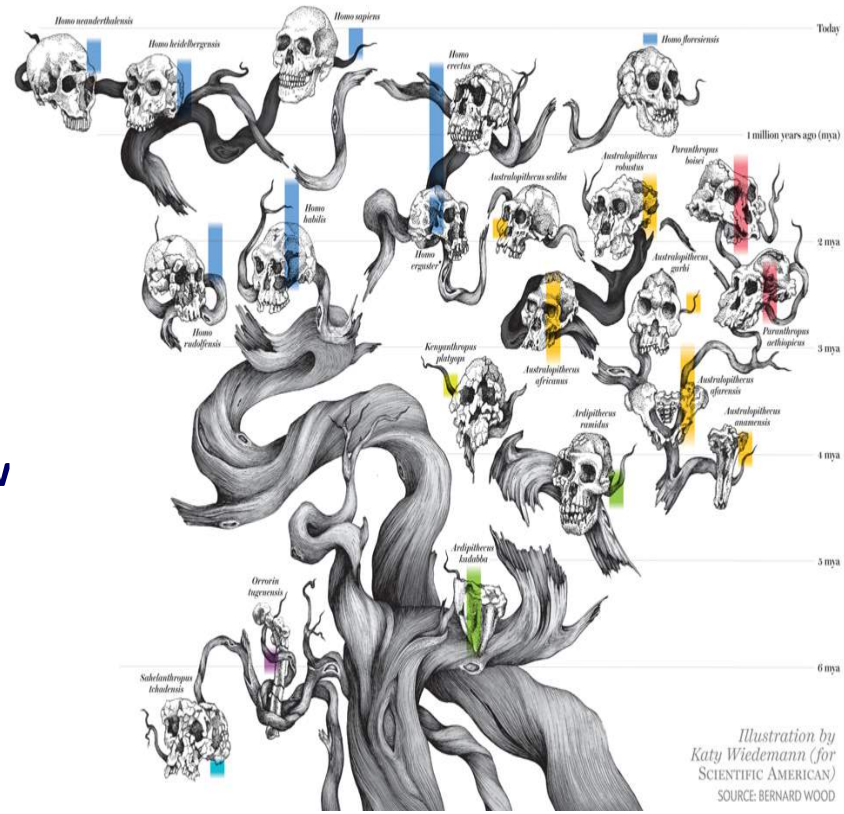
Gut

- smaller teeth and stomach, long small intestine around 1.8 million years ago
- shift from a high-volume, low-energy to low volume, high-energy diet

Aerobic capacity

- increased around 2 million years ago

Earliest known date for *H. sapiens* is 195,000 years ago



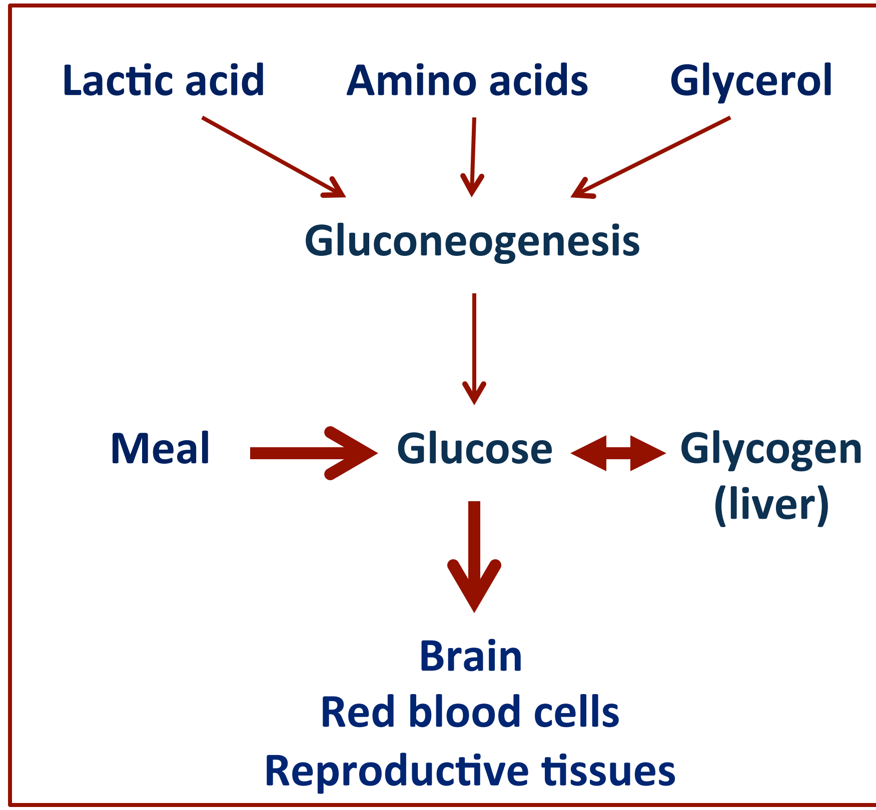
Source: WHERE WE CAME FROM. Scientific American, 00368733, Sep2014, Vol. 311, Issue 3

Evidence from nutrition – humans need dietary glucose

- About 150 g/day of glycemic carbohydrate needed from the diet
  - additional requirements for pregnant and lactating females

- Protein ceiling - humans can derive only 35-40% of energy from proteins

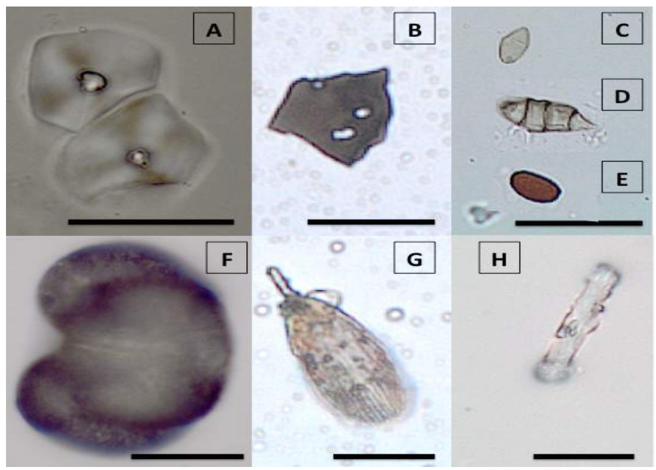
- Gluconeogenesis can meet 20-30% of the needs for glucose



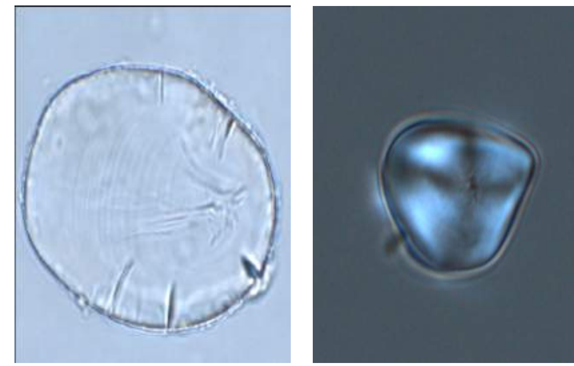
Evidence from archaeology – dental calculus

- **Dental calculus contains information on early hominin diet**

Starch in dental calculus



A, starch granules; B, microcharcoal; C, D, E, fungal spores; F, pine pollen grain: G, epidoptera wing scale; H, phytolith.



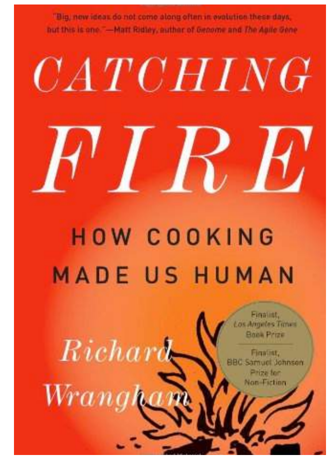
Neanderthal starch (*ca* 50,000 years old)

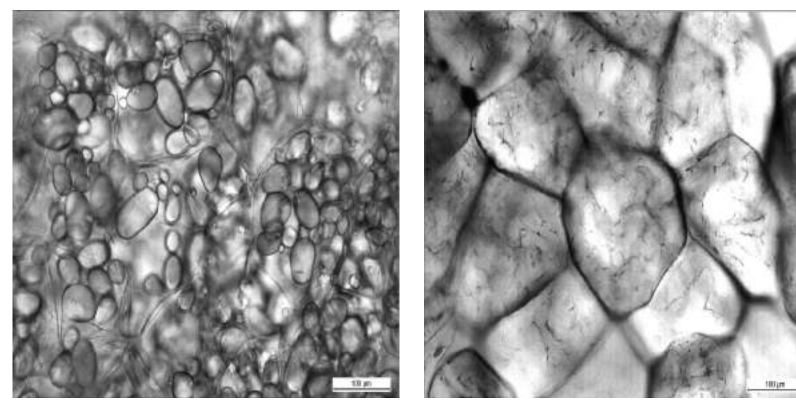
Amylolysis of ancient starch granules

Hardy et al. 2012. Naturwissenschaften 99, 617-626
Hardy et al. 2016. Quaternary International 398, 129-136

Cooking

- Humans are the only species that cook food
  - transformational event in human evolution
  - linked to emergence of social behavior
- Firm evidence of fire for cooking 300,000 - 400,000 years ago
  - may have occurred 800,000 years ago
- Improved palatability and digestibility of food
- Cooked starch greatly increased availability of energy and glucose for tissues with high glucose demand
  - large brain too costly energetically to function on a raw diet
  - earlier weaning and shorter inter-birth intervals





Starch granules in raw and cooked potatoes
(From Kai Lin Ek 2014. Univ of Sydney PhD Thesis)

Amylases

- Humans have salivary (*AMY1*) and pancreatic (*AMY2*) α-amylases
  - only *H. sapiens* have between 2 and 20 gene copies of AMY1
  - other primates have only 2 copies
  - more amylase means greater ability to digest starch

- Multiplication of *AMY1* genes
  - thought to have begun less than 1 million years ago
  - overlaps the time frame for hominin adoption of fire for cooking and enlargement of brain

- Cooking-driven increase in the availability of digestible starches would have provided evolutionary selection pressure for *AMY1* and *AMY2* copy number variation

- Individuals from populations with high-starch diets have, on average, more *AMY1* copies than those with traditionally low-starch diets

- Higher *AMY 1* copy number results in higher blood glucose response (Fiona Atkinson and Jennie Brand-Miller)

Role of starch in human evolution

Co-evolution of cooking and copy number variation of *AMY1* (and possibly *AMY2*) gene(s) increased availability of glucose, permitting the acceleration in brain size increase observed from the Middle Pleistocene

- **explains how our human ancestors were able to meet the greatly increased needs for glycemic energy**
- **unifies evidence from archaeology, prehistory, human physiology, nutrition and genetics**

Thank you for your attention







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