

# Concepts of Biology: BIOL 310

## Study guide for Exam 2

Alexey Shipunov

Lectures 1–19

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## Outline

# 1 Course in general

## 1.1 Description

### Course description

The field of ethnobotany studies the uses of plants by humans. This course will focus on the diversity of plant uses, covering approaches of diverse cultures, including plant uses specific to North Dakota, especially plant uses of Native Americans. Objectives are that students:

- will have integral picture of plant uses and their respective cultural background/histories;
- will be able to analyze information accompanying different plant-based products (including pharmaceutical);
- will know basic principles of plant cultivation, useful plant identification and survival based on plant use.

Students will demonstrate this knowledge in a classroom presentation at the beginning of lectures. Laboratories will concentrate on plant cultivation, collection, identification and databasing.

## **Instructor**

- Dr. Alexey Shipunov
- Office: Moore 229
- Office Hours: Mondays, Wednesdays and Fridays, 10 a.m. to 11 a.m.
- Phone: 858-3116
- E-mail: [alexey.shipunov@minotstateu.edu](mailto:alexey.shipunov@minotstateu.edu)

**Lectures** Mondays, Wednesdays and Fridays, 9:00 a.m. to 9:50 a.m., Moore 211

**Laboratories** Tuesdays and Thursdays 1:00 p.m. to 3:00 p.m., Moore 213

Lab sections will be additionally split to fit in the greenhouse. In some cases, labs will be spread over the weekdays. We also will have two outdoor excursions which last longer.

**Textbook : None.**

**Reference texts :** Several reference texts will be available on-line. Another reference (Heinrich et al. 2012. Fundamentals of Pharmacognosy and Phytotherapy) covers the pharmacognosy part of course. For the basic knowledge of botany, the on-line textbook “Introduction to Botany” (draft) is available.

**Course Web site**



## BIOL 310: Ethnobotany



### Course materials:

- [Syllabus](#) (PDF, 0.14 Mb)
- Reference: [Introduction to Botany \(textbook, draft\)](#) (PDF, 10 Mb)
- Reference: [P. Zhukovskij "Cultivated plants and their wild relatives"](#) (DjVu\*, 3.5 Mb)
- [Lecture 1](#) (PDF, ... Mb)
- [Old lectures](#) (2011)
- [Old lectures](#) (2013)
- [Guidelines for Ethnobotany projects](#) (PDF, 0.1 Mb)

*\*DjVu is similar to PDF, but much smaller in size and created in AT&T specifically for scanned books. To read it, download and install viewer from [here](#) (Windows and Mac OS) or [here](#) (for Windows, Mac OS and Linux).*

[Back](#)

[http://ashipunov.info/shipunov/school/biol\\_310/](http://ashipunov.info/shipunov/school/biol_310/)

## 1.2 Grading

### Exams

- **Four** exams are given during the semester.
- Only the **three best exams** contribute to the final grade.
- Missed exams count zero points. There are **no make-up** exams.

### Labs

- Receiving zero points for more than one laboratory results in a **failed course**.
- Grading of laboratories is based on reports and/or drawings.
- Written reports and/or drawings are prepared and finished during laboratory sessions and passed to the instructor right after the particular laboratory session.

## Absence

There are five legitimate reasons for absence:

1. emergency situations,
2. attested medical conditions,
3. military duty,
4. participation in MSU sports events,
5. dependent sick leave.

Absence from exams or laboratories must be announced to me in advance. I strongly recommend to attend lectures regularly since lectures are the main reference.

## Presentations

- Every Wednesday lecture will start from a short (10 min / 8 slides) presentation(s) and degustation (tasting) of cultivated plant.
- Every student in a class will have a **project** including this presentation, tasting, and growing the plant in the greenhouse.
- Presentation is mandatory and counted as an exam. Growing the project plant is considering as a lab part.
- List of plants for presentations and guidelines will be available for download on the Web site.

## Points

A total of  $\approx 540$  points can be earned and are distributed as follows:

**Three best exams** :  $\leq 240$  points (assuming 80 points per exam)

**Presentation** :  $\leq 80$  points

**Laboratories** :  $\leq 240$  points (20 points per lab  $\times$  12 labs)

Grading points may vary between exams and labs.

## Grades

- $A \geq 90\%$
- $B \geq 80\%$
- $C \geq 70\%$
- $D \geq 60\%$
- $F < 60\%$

A **minimum** of one letter grade will be deducted from the grade for academic dishonesty / plagiarism.

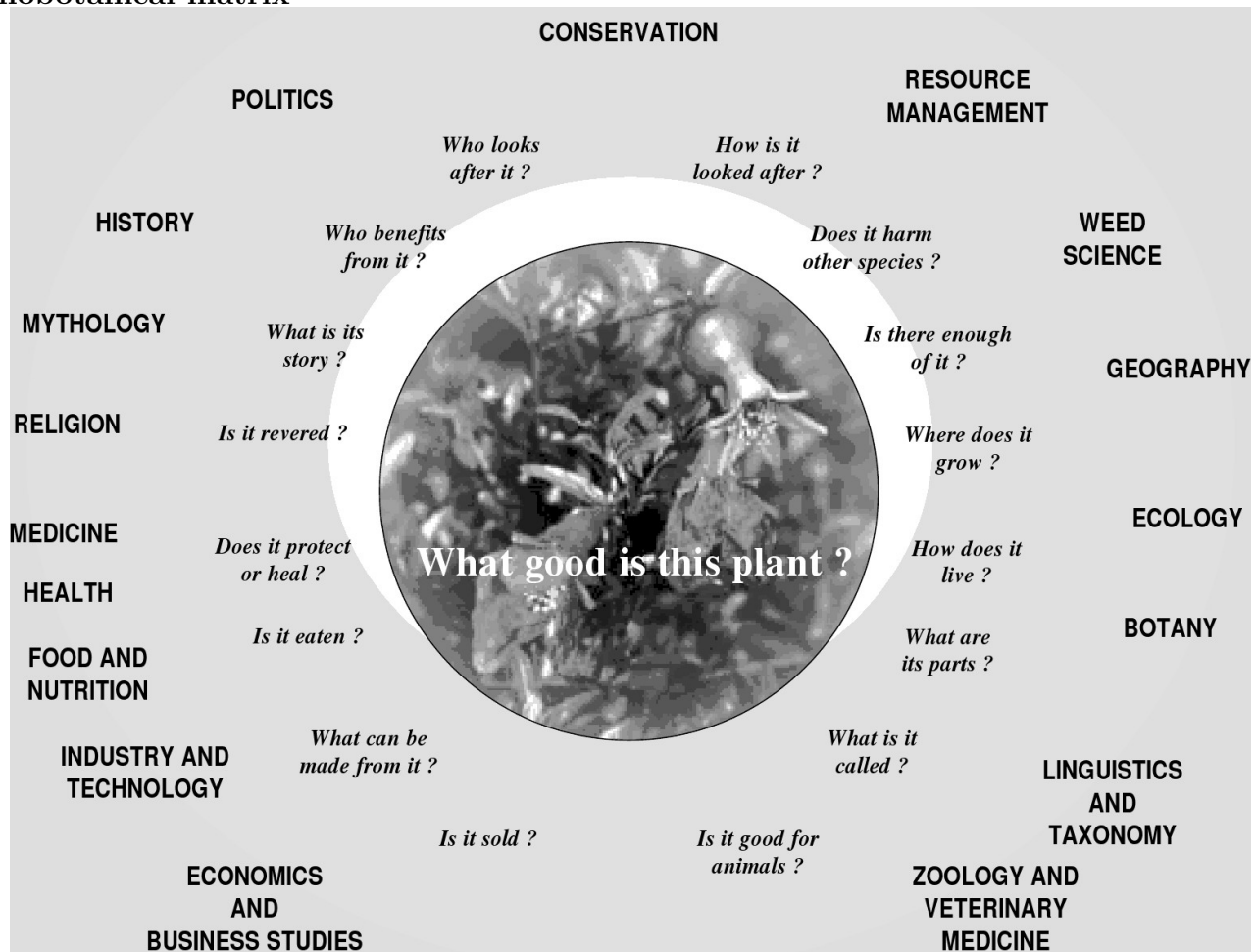
## 2 Ethnobotany

### 2.1 Introduction

#### Ethnobotany in general

- Ethnobotany is not a “pure” science, it is a multidisciplinary approach on the boundary of botany, genetics, evolution, history, anthropology and sociology
- It may be taught in strikingly different ways, and each ethnobotany course is different
- We will concentrate on plant uses along with evolutionary and historical aspects, and will emphasize the use of plants by Native Americans and useful prairie plants of North Dakota

#### Ethnobotanical matrix



### 2.2 Classification

#### Basics of scientific classification

- Every plant belongs to several embedded taxonomic groups
- Every group has **name** and **rank**
- Names usually are one Latin word, but species have **binary names**: name of genus + species epithet

- Most important ranks are (in sequence from bigger to smaller): **kingdom**, **family**, **genus** and **species**
- In addition, we will sometimes deal with **subspecies**, **variety**, and **cultivar**. The last is especially important for ethnobotany.

### Taxonomic framework for cultivated plants

- All plants belong to its own kingdom, Vegetabilia.
- Most of cultivated plants are angiosperms (flowering plants, Angiospermae).
- In most cases, we will need to **memorize the family** of plant. This is important characteristic since families are stable natural units of common evolutionary origin.

### Homework

- Download project guidelines, choose **3** plants
- Also, create your 6-digit class ID
- I will collect these on the next lecture
- Ethnobotany in a compound science including all aspects of plant use.

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)

### Outline

#### Homework

- Choose **3** plants from the project guidelines
- Create your 6-digit class ID

#### Reference books

Several reference texts will be available on-line. Another reference (Heinrich et al. 2012. Fundamentals of Pharmacognosy and Phytotherapy) covers the pharmacognosy part of course. For the basic knowledge of botany, the on-line textbook “Introduction to Botany” (draft) is available.

## 3 Ethnobotany

### 3.1 Classification

#### Subspecies, varieties and cultivars

- Subspecies is in essence the geographic race. Example: stinging nettle in Eurasia and North America, latter is *Urtica dioica* subsp. *gracilis*
- Variety is any distinguishable local variation. Example: bigger plantain with branched inflorescence, *Plantago major* var. *paniculata*
- Cultivar is a stable cultivated variety. Example: yellow roses, *Rosa banksiae* cv. ‘Lutea’

#### Subspecies, varieties and cultivars

- Names of species and subspecies should be *italicized*.
- Genus name, first word of species name and cultivar name should be uppercased, others—lowercased.
- Binary species names are not perfect IDs because they change every time we change genus for the particular species.
- Programmers came up with UUID solution (like “urn:lsid:ipni.org:names:321286-2” for *Plantago major*), but these UUIDs are unfortunately not human-readable.

#### Taxonomic framework for cultivated plants

- All plants belong to its own kingdom, Vegetabilia.
- Most of cultivated plants are angiosperms (flowering plants, Angiospermae).
- In most cases, we will need to **memorize the family** of plant. This is important characteristic since families are stable natural units of common evolutionary origin.
- Families were first established by practical botanists, and proved to be extremely stable taxonomic groups, even when molecular tools came to science

#### Folk classification

- Folk classification is an ancient approach to plant diversity
- Folk taxonomic groups are created artificially, mainly for practical use (like “edible”/“non-edible”)
- Typically, plant in folk classification belongs to so-called “genus-species” and then to bigger group. As an example, “raspberry” is genus-species and it in turn belongs to “berries”. In science, raspberry is a group of species in genus *Rubus* which belongs to Rosaceae family.

## Artificial classification of plant uses

This artificial classification will serve as a course plan:

1. **Main** plants (most important food sources): grains, starch-containing, legumes
2. **Sugar and oil** plants
3. **Fruits and vegetables**: fruits, vegetables, nuts
4. **Technical**: fiber, wood, latex, dye, feeding
5. **Aromatic and psychoactive**: spices, stimulating, narcotic
6. **Medicinal**: vitamin, ethereal oil, glycoside, alkaloid etc.
7. **Ornamental**: outdoor annuals, perennials, trees and shrubs, cut plants, indoor pot plants

## 4 Main food source plants: grains

### 4.1 Introduction to grasses

#### Grasses (Gramineae, or Poaceae)

- One of the biggest family of flowering plants
- Grasses (except bamboos)
- Hollow stems
- No main root, underground rhizomes form tussocks
- Compound inflorescences
- Simplified, wind-pollinated flowers
- Fruit is *caryopsis*, seeds should be *threshed* from fruits

#### Groups inside a family

- C<sub>3</sub> grasses—bamboos, wheat (*Triticum*), rye (*Secale*), barley (*Hordeum*), rice (*Oryza*), indian rice (*Zizania*), oat (*Avena*)
- C<sub>4</sub> grasses—corn (*Zea*), sugar cane (*Saccharum*), sorghum (*Sorghum*), millet (*Panicum*)

#### C<sub>3</sub> and C<sub>4</sub> plants

- C<sub>3</sub> plants have photosynthesis effective when temperatures are “cool”, below 24° C; if temperature increases, photorespiration makes photosynthesis ineffective
- C<sub>4</sub> plants show much better results growing on temperatures higher than 24° C; they are best suited for tropics
- In the ethnobotany course, we will approach plants in accordance with artificial classification of plant uses

# References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)

## Outline

### Reference books

Reference “Heinrich et al. 2012. Fundamentals of Pharmacognosy and Phytotherapy”: check the bookstore next week.

## 5 Main food source plants: grains

### 5.1 Introduction to grasses

#### Triticeae tribe

- Tribe is a taxonomic group which is bigger than genus but smaller than family
- Triticeae are small-sized grasses with one spike per stem, spike scales with long awns, caryopses rounded, contain high percent of starch and little amounts of proteins
- Several wild genera (most important are *Aegilops* and *Agropyron*: bluegrass and wheatgrass), and cultivated **wheat** and **rye**

### 5.2 Wheat (*Triticum*)

#### Main features

- One of three most important plants ever
- 30% of world grains
- Yield is up to 2.4 tonnes/hectare (2,400 kilograms per 10,000 m<sup>2</sup>); Guinness book record is 21 ton/ha (New Zealand, 2010)
- Main source of breads and bread-like products (similar products from other grains are growing hard much faster mostly because of more proteins)
- 70-75% of hydrocarbonates (starch) and 10% of proteins; 100 g give  $\approx$  350 calories
- However, wheat is not a rich source of lysine (indispensable amino acid), therefore, it is important to eat protein sources if menu is rich of wheat (pizza!)

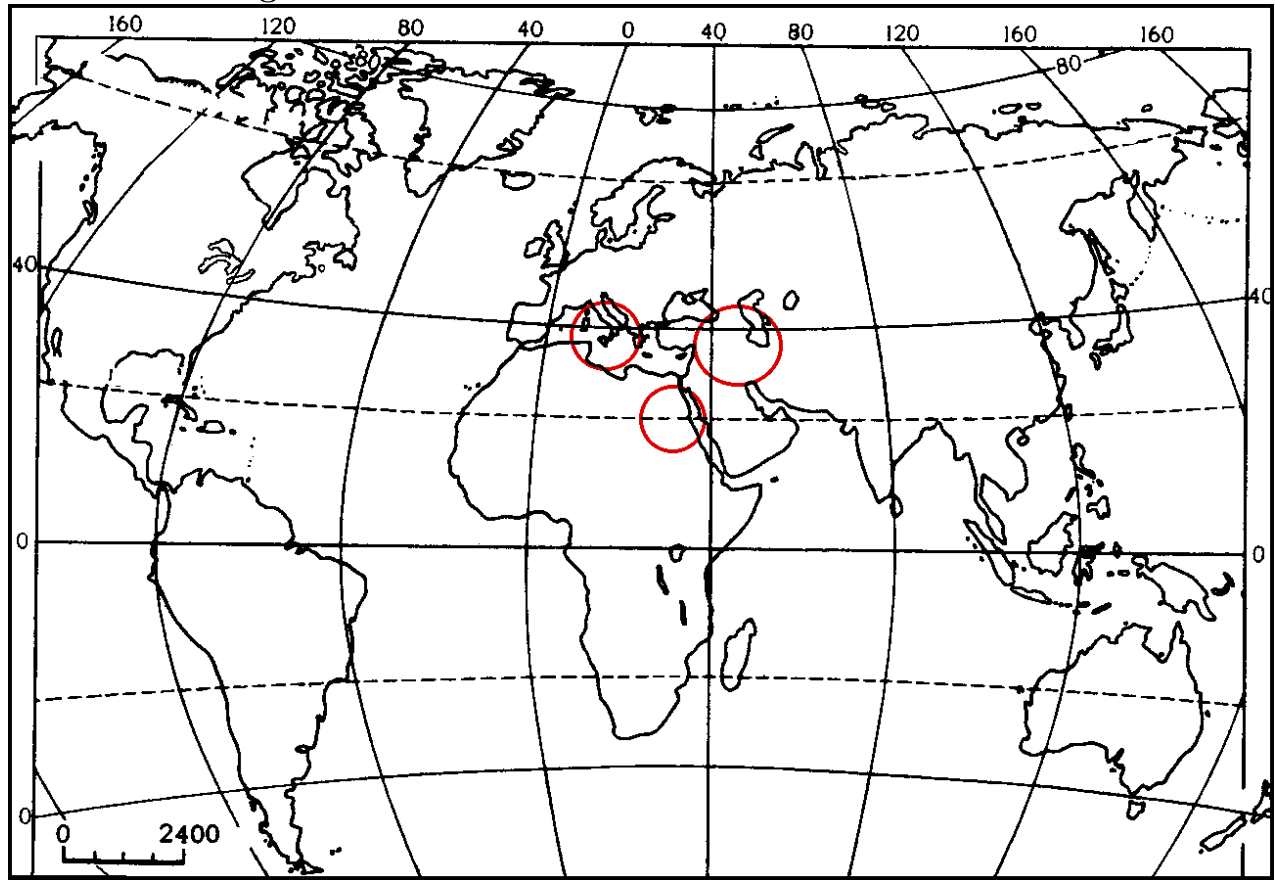
#### Morphology of wheats

- Annuals, root system of secondary and especially adventive roots
- From 1–6 long stems with spikes per plant
- Flowers have 3 stamens
- Both wind- and self-pollinated
- Genus has more than 20 species

## History of cultivation

- One of the most ancient cultivated plant, first traces date  $\approx 6\text{--}7,000$  yr ago
- Main centers: West Asia (Iran, Mesopotamia and Caucasus) and ancient Egypt
- During the history, “ancient” species (like eincorn) cede to “modern” species (like hard wheat)

## Centers of wheat origin and cultivation



## Features of wheat agriculture

- Wheats are well adapted to relatively dry regions, with amount of precipitation 600–800 mm per year (sometimes survive even with 400 mm)
- Easily endure small (!) droughts
- Temperatures for flowering should be in  $18\text{--}28^{\circ}\text{C}$  range; seedlings may survive under a snow; do not like high temperatures and do not give high yield in tropics (however, do not grow well in cold regions)
- Most critical for cultivation is the soil quality: should be light, well-aerated, rich of nitrogen (this is why wheats grow better after legumes)



## Species and species groups

- Diploid species ( $2n = 14$ ): eincorn
- Tetraploid species ( $2n = 28$ ): emmer wheat, hard wheat
- Hexaploid species ( $2n = 42$ ): common wheat

Common wheat ia a “genetic monster” with the chimeric genome.

## Summary

- Wheats (*Triticum*) are ancient cultivated plants, originated in West Asia
- Tetraploid and hexaploid wheats are intergeneric hybrids

## For Further Reading

## References

- [1] P. Stamp. *Virtual cereal cultivar garden* [Electronic resource]. 2008. Mode of access: <http://www.sortengarten.ethz.ch/?content=start>
- [2] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)

## Outline

### Lab 1

Most important logical paths:

- Well-manifested plant parts correlate with some uses (e.g., overgrown root correlates with medicinal and vegetable uses)
- Similarity with known plants is a source of estimation for uses (family grounds are most productive here)
- Interpretable hints on some images (humans together with plants)

The most safe classification groups:

- Vegetables (root, leaf/stem)
- Fruits
- Ornamental
- Harmful

## 6 Main food source plants: grains

### 6.1 Introduction to grasses

#### Species and species groups

- Diploid species ( $2n = 14$ ): eincorn
- Tetraploid species ( $2n = 28$ ): emmer wheat, hard wheat
- Hexaploid species ( $2n = 42$ ): common wheat

Common wheat is a “genetic monster” with the chimeric genome.

#### Spring and winter races

- Most cultivated species have two races
- *Winter race* does not flower if planted in spring; it typically grows under a snow and should be planted in autumn
- *Spring race* does not survive under snow; it should be planted in spring
- These two forms are partly genetically inherited; it is possible, however to change behavior from winter to spring (vernalization: hard selection + epigenetic effects)

### 6.2 Ancient wheats

#### *Triticum monococcum*

- Eincorn, or *Triticum monococcum* is probably the most ancient cultivated plants ever (cultivated from neolithic age)
- Do not require irrigation, survive with low precipitation but yield is also low
- In spikes, spikelets have only one flower
- Relatively tall (up to 1 m)
- Now cultivated rarely, one of the last centers of cultivation is Spain

Eincorn, *Triticum monococcum*



### *Triticum dicoccum*

- Emmer wheat (farro, *Triticum dicoccum*) has fragile spike and more than one flower per spikelet
- Sustainable for droughts, bacterial and fungal infections, insects, lower temperatures but has extremely low yield
- Still cultivated in some European countries (Italy, Albania); main food source in Ethiopia
- Used also as a genetic source for hybridization and selection

**Emmer wheat (*Triticum dicoccum*)**



### 6.3 “Contemporary” wheats

#### *Triticum durum*, hard wheat

- Hard wheat (*Triticum durum*) is a second most cultivated wheat, probably of Mediterranean origin
- Small-sized, fast-growing
- Almost exclusively self-pollinated
- Has high yield and grains of best quality among wheats containing more proteins

#### Hard wheat (*Triticum durum*)



### *Triticum durum* 2

- Winter races are rare
- Requires irrigation
- Better suited for cultivation in tropics
- The highest diversity is now in Italy (widely used for a pasta!)
- Now widely cultivated in tropics (India, Africa)

### *Triticum aestivum*, common wheat

- Common (soft) wheat (*Triticum aestivum*) is a main cultivated wheat

- There are more than 4,000 cultivars of common wheat
- Small- and medium-sized but slow-growing when young
- Often cross-pollinated
- High yield, grains are rich of starch

Common wheat (*Triticum aestivum*)

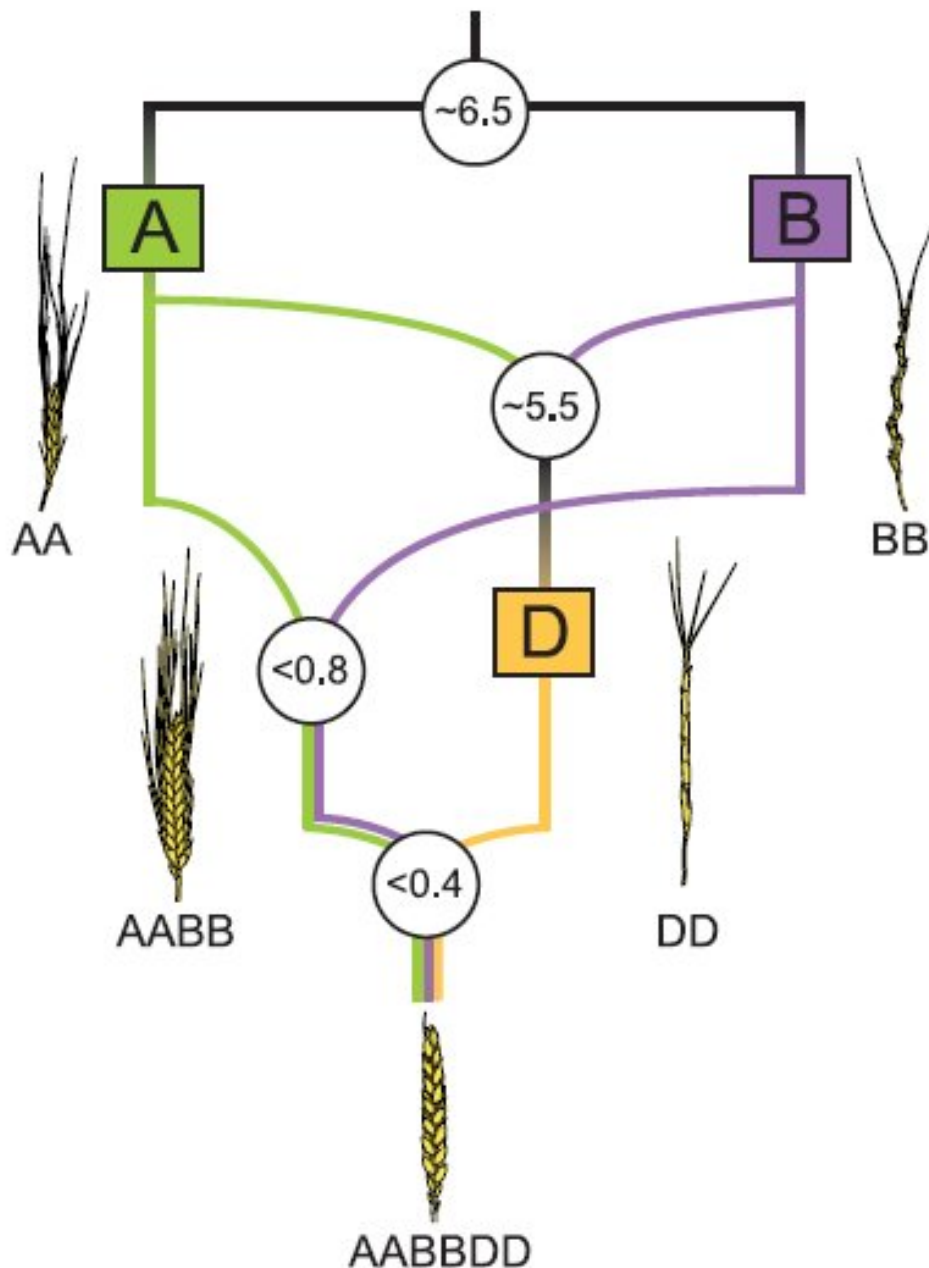


*Triticum aestivum* 2

- Has many winter and spring races
- Typically, does not require irrigation

- Cultivated mostly in temperate and subtropical regions around the world
- Main cultivated wheat in U.S.

### Origin of wheats



- Tetraploid and hexaploid wheats are **inter-generic hybrids** between diploid wheats and *Aegilops* (goatgrass)!
- Tetraploid wheats have genome AABB (A from diploid wheats, B from *Aegilops speltoides*)
- Hexaploid wheats have genome AABBDD (D from *Aegilops tauschii*)

### Summary

- Wheats (*Triticum*) are ancient cultivated plants, originated in West Asia

- Tetraploid and hexaploid wheats are intergeneric hybrids

## For Further Reading

## References

- [1] P. Stamp. *Virtual cereal cultivar garden* [Electronic resource]. 2008. Mode of access: <http://www.sortengarten.ethz.ch/?content=start>
- [2] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)

## Outline

# 7 Main food source plants: grains

## 7.1 Wheat, *Triticum*

### Species and species groups

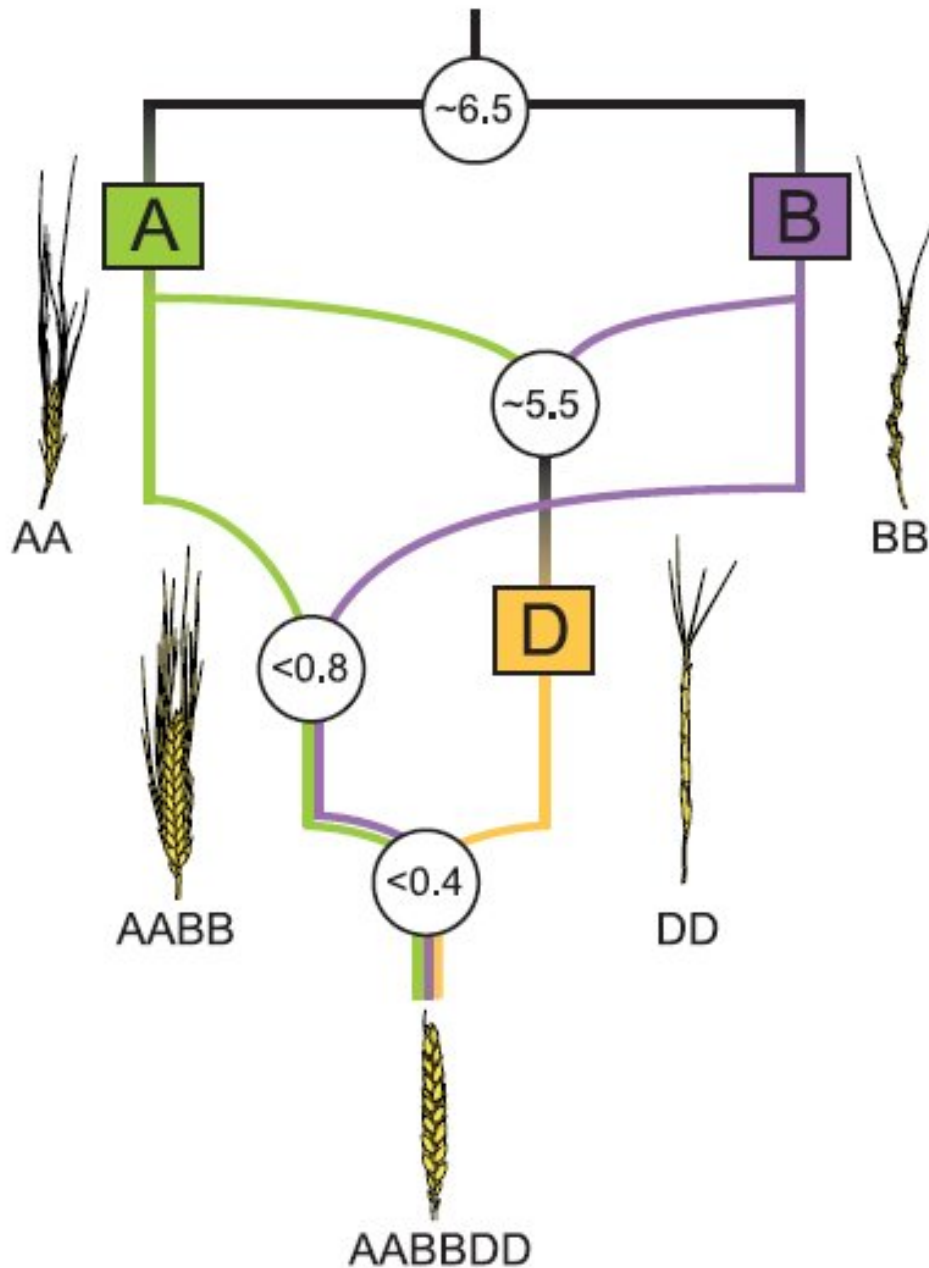
- Diploid species ( $2n = 14$ ): eincorn
- Tetraploid species ( $2n = 28$ ): emmer wheat, hard wheat
- Hexaploid species ( $2n = 42$ ): common wheat

Common wheat ia a “genetic monster” with the chimeric genome.

## 7.2 “Contemporary” wheats

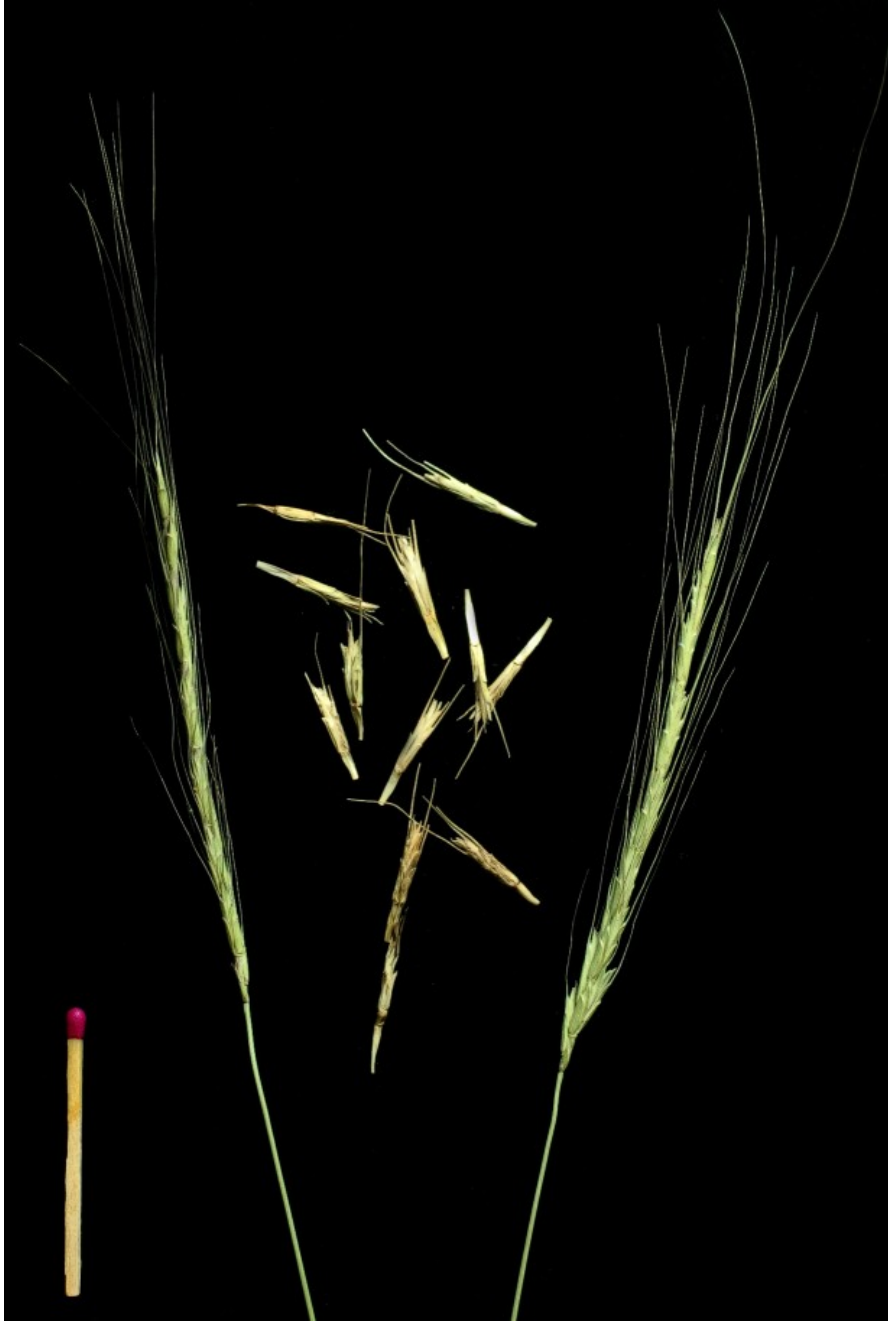
### Origin of wheats





- Tetraploid and hexaploid wheats are **inter-generic hybrids** between diploid wheats and *Aegilops* (goatgrass)!
- Tetraploid wheats have genome AABB (A from diploid wheats, B from *Aegilops speltoides*)
- Hexaploid wheats have genome AABBDD (D from *Aegilops tauschii*)

*Aegilops speltoides*



*Aegilops tauschii*



Norman Borlaug, University of Minnesota, 1914–2009



Father of “green revolution”, Nobel Prize (1970)

### Norman Borlaug started contemporary wheat selection

- Dwarf wheats (especially in common wheat) are selected with transition from sickle to harvesting machines, they withstand many weather problems and are more drought-resistant
- Wheats with branched spikes (based on tetraploid *Triticum turgidum*, rivet wheat and hybrids)
- Octoploid forms ( $2n = 56$ ) are artificial, typically have bigger grains
- Hybrids with rye,  $\times$  *Triticosecale* (*Triticum*  $\times$  *Secale*)

### Rivet wheat, *Triticum turgidum*



× *Triticosecale*





## 8 Other $C_3$ grains

### 8.1 Rye

Rye, *Secale*

- Belongs to the same tribe with wheat, Triticeae
- Much “younger” cultivated plant
- Cultivated mostly in temperate regions of Eurasia (Russia, Germany, Sweden) and Canada

**Rye features**

- Hardy plant, likes sandy soils, survives with a frost, has a short life cycle adapted for long days, however, yield is low,  $\approx 1$  ton/hectare
- Many winter cultivars
- Cross-pollinated
- Rich of proteins, therefore rye bread is growing hard faster than pure wheat bread; typically, rye bread contains wheat additives (sometimes up to 70%)
- Has multiple uses: as a forage plant become available early in the spring, as a source of ethanol, as a source of straw

## Rye taxonomy

- Several species, only one is cultivated: *Secale cereale*
- Has two subspecies: one is a cultivated rye, *Secale cereale* subsp. *cereale*, second is a weed (occurring mostly in wheat crops): *Secale cereale* subsp. *segetale*
- Chromosome number is diploid ( $2n = 14$ ), similar to primitive diploid wheats

## Rye origin and history

- Weed rye originated from wild species and become annual (other ryes are perennial) in order to correspond with wheat life cycle
- Cultivated rye is a domesticated weed rye
- N. Vavilov stated that rye outperformed wheat on the northern slopes of Caucasus mountains where spring may come two months later than on southern slopes; this competition sometimes resulted in pure rye crops
- Than selection started for bigger grains, since rye is cross-pollinated, selection went faster
- First remains of rye dated 300–400 AD (Black Sea coast)
- Since rye has open flowers, it sensitive to ergot (*Claviceps purpurea* fungus) containing hallucinogenic lysergine acid which was the cause of ergotism disease in medieval centuries. In times of the “small ice age” (13–18 centuries), when wheat in most of Europe was replaced with rye, ergotism was probably the reason of the widespread “witch hunting”.

## Cultivated rye, *Secale cereale* subsp. *cereale*



[Note the dark ergot (*Claviceps purpurea*) fruiting bodies]

Weed rye, *Secale cereale* subsp. *segetale*





## 8.2 Barley

Barley, *Hordeum*

- Belongs to the same tribe Triticeae
- Plant of multiple use: as bread (rarely), as a cereal, for making beer, as a forage plant
- Old West Asian culture, now cultivated mostly in temperate regions of North Hemisphere

### Barley features

- Grains are not fully appropriate for bread, they have too high amount of proteins ( $> 7\%$ ), resulted in bread which is crumbling too much

- Hardy plant, survives easily in winter (there are many winter cultivars), has extremely fast life cycle and therefore cultivated on high altitudes in mountain areas (as Tibet)

### **Barley taxonomy**

- Almost 40 species, only two are widely cultivated
- *Hordeum distichon*, two-rowed barley, is cultivated mostly for beer production; spike has two rows of spikelets
- *Hordeum vulgare*, six-rowed barley, cultivated for multiple purposes; six rows of spikelets
- These species are sometimes treated as one

### ***Hordeum distichon*, two-rowed barley**

- Old culture (7,000 BC) from West Asia and Egypt, originated from wild *Hordeum spontaneum*
- Annual, with flat spikes
- Only spring forms
- Now cultivated mostly in West and Middle Asia and Europe

### ***Hordeum vulgare*, six-rowed barley**

- Newer culture, 4–5,000 BC, originated from East Asia
- China and Japan are still centers of diversity (and probably, centers of origin)
- Goes very high on mountains, up to 6,000 m above sea level
- Widely cultivated, the yield is comparable to the contemporary wheats ( $\approx 2$  ton/ha)
- Unfortunately, sensitive to drowning and to fungal diseases, especially to powdery mildew (*Erysiphe* spp.)

### **Role in brewing**

- For brewing, barley grains are malted: germinated by soaking in water and then sharply drying by hot air
- Consequently, enzymes started to modify starch into mono- and disaccharides, such as fructose, glucose, sucrose and maltose
- These saccharides are used for making wort (mixture of malted barley with water); wort is then fermented with brewer yeasts (*Saccharomyces cerevisiae* fungus)

Two-rowed barley, *Hordeum distichon*



Six-rowed barley, *Hordeum vulgare*



Ancestor of barley, *Hordeum spontaneum*



### 8.3 Oat

#### Oat (*Avena*)

- Belongs to different tribe, Aveneae
- Morphology is also different: oats have branched inflorescence, panicle
- Several species in cultivation, as a forage plants (especially for horses) and as cereals

#### Oat features

- Hardy culture, cultivated mostly in temperate regions, yield relatively low, is  $\approx 1$  ton/hectare
- Grains contain high amounts of proteins and lipids

- Mostly spring forms (winter cultivars also exist); life cycle longer than in barley (should be planted earlier in a spring)
- Not sensitive to many fungal diseases

### **Oat taxonomy**

- Several dozens species, only two are widely cultivated
- *Avena byzantina*, red oat, is more hardy and also better adapted to dry climates, has long grains
- *Avena sativa*, common oat, main cultivated oat, has shorter grains

### **Origin of oats**

- Red oat is a domesticated form of wild oat, *Avena sterilis*. Cultivation started with invention of big cavalry armies ( $\approx$  400 BC) of Alexander the Great
- Common oat was the weed of emmer wheat (*Triticum dicoccum*), and became pure culture when crops went northward (similar to rye)

### **Red oat, *Avena byzantina***



Common oat, *Avena sativa*





Oat ancestor, *Avena sterilis*





## Summary

- Wheats (*Triticum*) are ancient cultivated plants, originated in West Asia
- Tetraploid and hexaploid wheats are intergeneric hybrids
- **Barley** is an ancient culture well adapted to agriculture in mountain regions
- **Rye** and **common oat** were originated from weeds

## For Further Reading

# References

- [1] P. Stamp. *Virtual cereal cultivar garden* [Electronic resource]. 2008. Mode of access: <http://www.sortengarten.ethz.ch/?content=start>
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## Outline

## Presentations

# 9 Main food source plants: grains

## 9.1 “European” grains

### Summary: “European” grains

- Wheats (*Triticum*) are ancient cultivated plants, originated in West Asia
- Tetraploid and hexaploid wheats are intergeneric hybrids
- **Barley** is an ancient culture well adapted to agriculture in mountain regions
- **Rye** and **common oat** were originated from weeds

## 9.2 Rice

### Rice (*Oryza sativa*)

- Belong to the tribe Oryzeae
- Has panicle as an inflorescence, flowers with 6 stamens (uncommon in grasses)
- More than half of human population use rice as a main food source
- Cultivated mostly in tropics and subtropics, below 42° latitudes

### Rice features

- High calories (360 cal / 100 g), up to 10% of proteins, including lysine amino acid (!)
- White (polished) rice does not contain embryo and therefore deficient of many vitamins; beriberi disease is a deficiency of vitamin B<sub>1</sub> (thiamine) originated in richer families of Indonesia (because they were wealthy enough to buy a “better” rice)
- Rice is not used for bread, if cooked it become extremely brittle
- Yield is higher than wheat,  $\approx 6$  ton/hectare
- Rice is a coastal plant, requiring water, especially when young; seedlings are often manually planted in the soil covered with water
- Ancestrally, rice requires monsoon climate: first season is wet (rice germinates), second is dry (rice matures)

## Summary

- Rice is the old culture with extremely complicated agriculture but high yield

## For Further Reading

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## Outline

# 10 Questions and answers

## 10.1 Lab 2

### Lab 2: most important notes

- Compound leaves *vs.* stem with simple leaves
- Roots *vs.* underground stems (rhizomes *etc.*)

# 11 Main food source plants: grains

## 11.1 Rice, *Oryza sativa*

### Rice features

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- White (polished) rice does not contain embryo and therefore deficient of many vitamins; beriberi disease is a deficiency of vitamin B<sub>1</sub> (thiamine) originated in richer families of Indonesia (because they were wealthy enough to buy a “better” rice)
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- Ancestrally, rice requires monsoon climate: first season is wet (rice germinates), second is dry (rice matures)

## Rice taxonomy

- 28 species, only one is widely cultivated: *Oryza sativa*, common rice
- Several main varieties, including Japanese (short-grain) and Indian (long-grain) rice. Japanese variety has sticking (high proteins) and non-sticking forms.

## Rice origin and history

- First remains (Thailand) are 7,000 BC; mass cultivation started in East Asia 4–5,000 BC
- Most probably, perennial *Oryza perennis* is a wild relative of cultivated rice
- Came to Europe with Arabs in first millennium
- From 1865, is cultivated in U.S. (first plantations in North Carolina)
- After the “Green Revolution” in 1960s, genetically modified rice cultivars allow to finish hunger in India and China

## Rice agriculture

- Seeds are germinated in nurseries
- After several weeks, seedling are transplanted (often manually) to flooded fields
- Water should be removed after 1–2 month from transplanting
- There are also “mountain” rice which does not require flooding (but its yield is less)

## Common rice, *Oryza sativa*



Rice flower



Ancestor of rice, *Oryza perennis*



## 12 Lesser C<sub>3</sub> grasses

### 12.1 Indian rice, *Zizania*

Indian rice, *Zizania*

- Small (3 species) genus of water grasses distributed in East Asia and North America
- Big (up to 1.5 m), partly submerged grasses with unisexual flowers
- Inflorescences are panicles
- Long grains



### *Zizania aquatica*, or manoomin

- Only one species was used by Native Americans
- Odjibwe name “manoomin”, Dakota name “psi”
- Half-cultivated (supported but not planted)
- Stems tied (precaution against birds), then harvested from canoe

#### Ricing, step 1



#### Ricing, step 2



Ricing, step 3





Ricing, step 4



Ricing, step 5: threshing



Ricing, step 6





## 12.2 *Digitaria exilis*, fonio

### *Digitaria exilis*, fonio

- Main crop of West Africa
- The only cultivated species of big ( $\approx 300$  species) genus *Digitaria*
- Low, heavily branched grasses
- Grains are extremely small (2–3 mm); however, the yield is comparable with primitive wheats (0.6–1 ton/ha)

### Fonio agriculture

- Well adapted to short days, high temperatures and low precipitation
- Needs only surface development of soil, planted by scattering
- Manual harvesting and threshing

### Fonio



Fonio threshing





Fonio grains



### 12.3 *Eragrostis tef*, tef

#### *Eragrostis tef*, or tef

- One of the main cultures of East Africa
- Used for making bread
- Small, branching plants with small spikelets and grains
- Grains are rich of iron (used also for medical purposed, for treating anemia)
- Well adapted to high altitudes
- Yield is comparable with rye ( $\approx 1$  ton/ha)



Tef



Tef grains





## 13 C<sub>4</sub> grains

### 13.1 *Zea mays*, corn

*Zea mays*, corn, maize

- The most important world grain (after wheat and rice)
- Mostly tropical, subtropical and warm temperate culture
- U.S. is a main corn producer (almost 50% of world production)
- Has a high yield: up to 8 tons/hectare
- Grains are rich of proteins (up to 20%) and oil (4–8%)
- Using for bread-like products, for making starch, sugar, as a forage plant, for making different secondary production (coal, ethanol, paper)

*Zea mays* morphology and taxonomy

- Unique grass, the sole member of genus *Zea*
- High (up to 6 m) annual with relatively small root system

- Has a highly modified inflorescences: terminal male are panicles whereas axillary female inflorescences have inflated axis and densely packed flowers
- Female flowers have extremely long styles (sometimes  $\approx 1$  m)
- Cross-pollinated
- Caryopsis big, round-shaped, with soft or glossy endosperm

### ***Zea mays* diversity**

- Four most common varieties:
- var. *microsperma*: small grains and corns, endosperm has two layers and used for popcorn
- var. *amylacea*: grains are rich of starch
- var. *dentiformis*: 70% of cultivated corn
- var. *saccharata*: rich of sugars, used for canned corn

### ***Zea mays* agriculture**

- Optimal temperatures are 25–30° C
- Needs a constant water supply and rich (especially with nitrogen and phosphorous) soil
- Most effective with crop rotation
- Likes short days, vegetation period up to 200 days

### **Summary**

- **Rice** is the old culture with extremely complicated agriculture but high yield
- Wild, or Indian rice was the only grain used widely in northern tribes
- Both fonio and tef are old African cultures with the relatively low yields

### **For Further Reading**

## **References**

- [1] P. Stamp. *Virtual cereal cultivar garden* [Electronic resource]. 2008. Mode of access: <http://www.sortengarten.ethz.ch/?content=start>
- [2] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)

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## Lab 3

### 14 C<sub>4</sub> grains

#### 14.1 *Zea mays*, corn

##### *Zea mays*, corn, maize

- The most important world grain (after wheat and rice)
- Mostly tropical, subtropical and warm temperate culture
- U.S. is a main corn producer (almost 50% of world production)
- Has a high yield: up to 8 tons/hectare
- Grains are rich of proteins (up to 20%) and oil (4–8%)
- Using for bread-like products, for making starch, sugar, as a forage plant, for making different secondary production (coal, ethanol, paper)

##### *Zea mays* morphology and taxonomy

- Unique grass, the sole member of genus *Zea*
- High (up to 6 m) annual with relatively small root system
- Has a highly modified inflorescences: terminal male are panicles whereas axillary female inflorescences have inflated axis and densely packed flowers
- Female flowers have extremely long styles (sometimes  $\approx 1$  m)
- Cross-pollinated
- Caryopsis big, round-shaped, with soft or glossy endosperm

## *Zea mays* diversity

- Four most common varieties:
- var. *microsperma*: small grains and cobs, endosperm has two layers and used for popcorn
- var. *amylacea*: grains are rich in starch
- var. *dentiformis*: 70% of cultivated corn
- var. *saccharata*: rich in sugars, used for canned corn

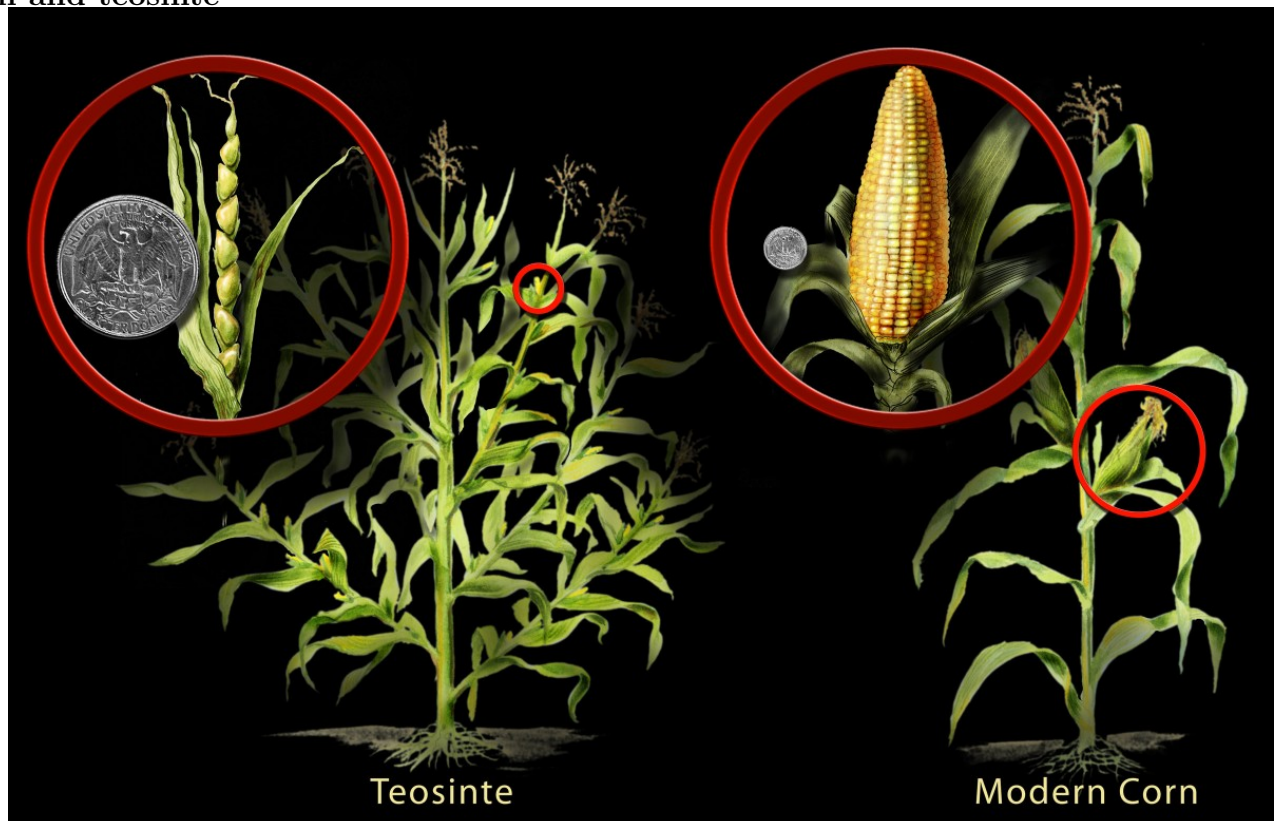
## *Zea mays* agriculture

- Optimal temperatures are 25–30° C
- Needs a constant water supply and rich (especially with nitrogen and phosphorous) soil
- Most effective with crop rotation
- Likes short days, vegetation period up to 200 days

## *Zea mays* origin

- No close relatives exist (!)
- Two related genera are *Teosinte* (teosinte) and *Tripsacum* (gama grass) which could cross with corn
- Most probably, wild ancestor became extinct  $\approx$  5,000 years ago

## Corn and teosinte





Teosinte



Tripsacum



### *Zea mays* history

- First remains from Mexico dated 3,400 years BC
- Most probably domestication started in Mexico and Central America independently
- All varieties already exist in pre-Colombian era, corn became widely cultivated from Canada to southern South America
- In 1492, Columbus wrote first notes about corn cultivation
- From XVI century, cultivation started in Africa, then in Europe and finally in Asia

## 14.2 *Sorghum*

### *Sorghum*, sorghum

- More than 30 species, many of them are cultivated
- Ancient culture (3,000 BC), started in Africa
- Now cultivated mostly in Asia and Africa, preferably in most dry and hot places
- Yield is around 3 tons/hectare

### **Sorghum morphology and agriculture**

- Tall (up to 1.5 m) grasses
- Inflorescences are dense panicles
- Small grains
- Requires high temperatures and short days
- Drought-tolerant, allows most kinds of soils
- Long growth period: 200 or more days
- Came to Asia  $\approx$  2,000 years ago, but cultivated in Europe and U.S. only for last 100 years

### **Sorghum diversity**

- *Sorghum bicolor*—grain sorghum, Africa
- *Sorghum durra*—white sorghum, India
- *Sorghum chinensis*—red sorghum, or gao liang, China

### **Sorghum**





Gao liang





### 14.3 Pearl millet, *Pennisetum*

#### Pearl millet, *Pennisetum*

- One cultivated African species, *Pennisetum glaucum*
- Forage and cereal culture, mostly in Africa and Asia
- Tall plant with compact cylindric panicle
- Undemanding culture, requires only warm temperatures and short days

#### Pearl millet



#### 14.4 Finger millet, dagusa, *Eleusine*

Finger millet, dagusa, *Eleusine coracana*

- Indian ancient crop (now cultivated also in Africa), sole species of genus
- Used as cereal
- Yield is comparable with wheat (2 ton/hectare)
- Requires aerated, humid soils and short days
- Resistant to fungal and bacterial diseases

**Finger millet**





## 14.5 Common, or proso millet, *Panicum*

Common, or proso millet, *Panicum miliaceum*

- Initially, ancient Chinese culture (2,500 BC)
- Grains are rich of proteins (14%)
- Requires short days but also has short cultivation time therefore cultivated up to 56° latitude
- Now cultivated mostly in East Europe, in U.S. only as a birdseed

**Proso millet**



Proso millet in Russian grocery store





Barley, buckwheat and proso cereals





Proso millet broom

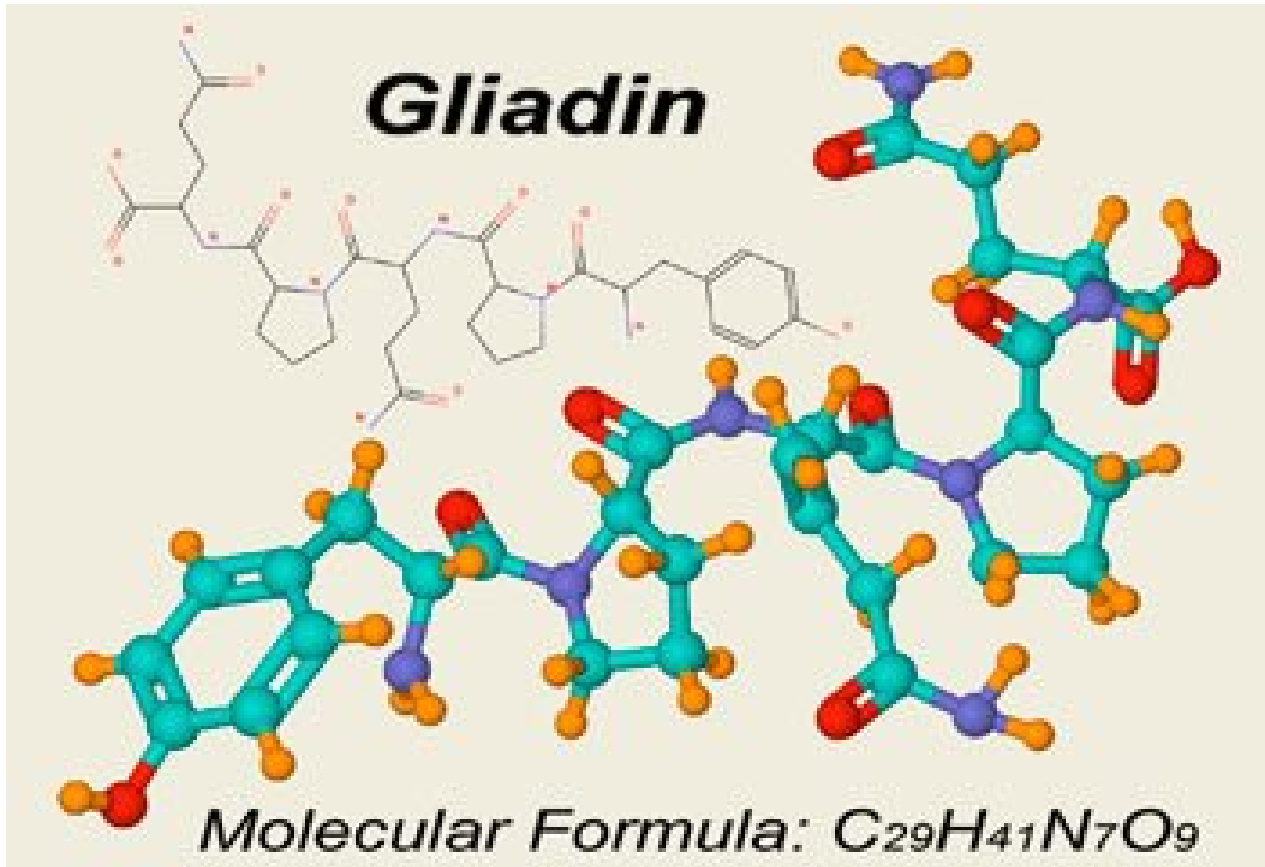


## 15 Non-grass grains, or pseudocereals

### 15.1 Buckwheat, *Fagopyrum esculentum*

Pseudocereals, gluten-free diet and celiac disease





- Wheat, rye and barley proteins (gluten) contain gliadin which is a main agent of autoimmune celiac disease ( $\approx 1\%$  of human population)
- C<sub>4</sub> grasses and pseudocereals are free of gluten and now are becoming main components of gluten-free diet

### Buckwheat, *Fagopyrum esculentum*

- Pseudocereals are not grasses but are using in similar ways, e.g., for flour, as “true” cereals, sometimes even for breads
- Buckwheat (*Fagopyrum esculentum* from Polygonaceae family) is one of the most important and old (6,000 BC) pseudocereal
- Green buckwheat (*Fagopyrum tataricum*) is the another cultivated species
- Yield is relatively low ( $\approx 1$  ton/hectare)
- In addition to grain production, one of the best nectar producers

### Buckwheat features

- Hardy plant (mountain origin!), but requires rich and relatively wet soils
- Two forms of flowers, with long and short styles: **heterostyly**. Therefore, strict cross-pollinator. Main pollinators are bees: minimum two hives per hectare required.
- Grains are rich of proteins and micro-elements (especially iron)

Buckwheat, *Fagopyrum esculentum*



Buckweed pollination and fruits



Buckwheat history

- Domesticated probably in Nepal (where is still used as nut) and spread across most of Eurasia
- Cultivated in Europe (especially Russia and France), China, Canada and northern U.S. (e.g., North Dakota)





## 15.2 Quinoa (*Chenopodium*) and other pseudocereals

### Quinoa (*Chenopodium quinoa*)

- Belong to Amaranthaceae family (close to buckwheat family)
- Originated in Andean region, used from 2,000 BC and was plant of main importance (more than corn, secondary only to potato) in Inca civilization
- Adapted to high altitudes, easily cultivated above 4,000 meters
- Yield is  $\approx 2$  ton/hectare
- Contain balanced sets of useful amino acids and microelements; could be used as a sole food even for long journeys
- Unfortunately, seeds contain weakly toxic and bitter *saponin* which should be removed before cooking (usually by soaking in water)

### Summary

- Widely cultivated  $C_4$  grasses are mostly ancient American (corn) or African (sorghum) cultures
- **Pseudocereals** are non-grass grains, plants from families other than Gramineae but used for same purposes

### For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)
- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

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## 16 Non-grass grains, or pseudocereals

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- Contain balanced sets of useful amino acids and microelements; could be used as a sole food even for long journeys
- Unfortunately, seeds contain weakly toxic and bitter *saponin* which should be removed before cooking (usually by soaking in water)

Quinoa, *Chenopodium quinoa*



Quinoa grains





### Other important pseudocereals

- South American qaniwa (*Chenopodium pallidicaule*) and North American (native for North Dakota!) pitseed goosefood (*Chenopodium berlandieri*) are both similar to quinoa
- Amaranth (*Amaranthus* spp. from Amaranthaceae): cultivated mostly in Europe and America, originated from Central America. Grains are highly diverse in microelements and rich of proteins
- Chia (*Salvia hispanica* from Labiatae): domesticated in Mexico, used by Aztecs. Grains are rich of diverse lipids and slime polysaccharides. Used also to make drinks. From 2008, recommended as “novel food” in European Union
- Whattleseed (*Acacia* spp. from Leguminosae): original grains of Australian Aborigines

### Amaranth, *Amaranthus* sp.



Chia, *Salvia hispanica*





Whattleseed, *Acacia* spp.



Australian millstone





## Summary

- **Pseudocereals** are non-grass grains, plants from families other than Gramineae but used for same purposes

## For Further Reading

## References

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## 17 Starch-containing plants

### 17.1 Potatoes, tuber species of genus *Solanum*

#### Potatoes, tuber species of genus *Solanum*

- *Starch* and *inulin*—polymers of glucose or fructose monosaccharides, respectively. Plants accumulate them mostly in underground parts: roots, rhizomes, tubers
- *Solanum* is one of the largest plant genera (up to 2,000 species!) and includes several important plants (tomatoes and eggplants) and potatoes—species from section **Petota** ( $\approx 15$  species, all produce “potatoes”).

#### Morphology and other features of potatoes

- Potatoes are **tubers**, enlarged parts of specialized rhizomes; buds grow into tubers in darkness
- Main function of tubers is vegetative propagation
- Yield of tubers is high,  $\approx 15$  ton/hectare, but 70–80% of it is a water
- Still, in calories yield is higher than rice or corn: every 100 g contain 15 g of carbohydrates
- There are almost no fats and low amounts (2%) of proteins
- Plants are cross-pollinated; fruits are toxic (contain *solanin*)

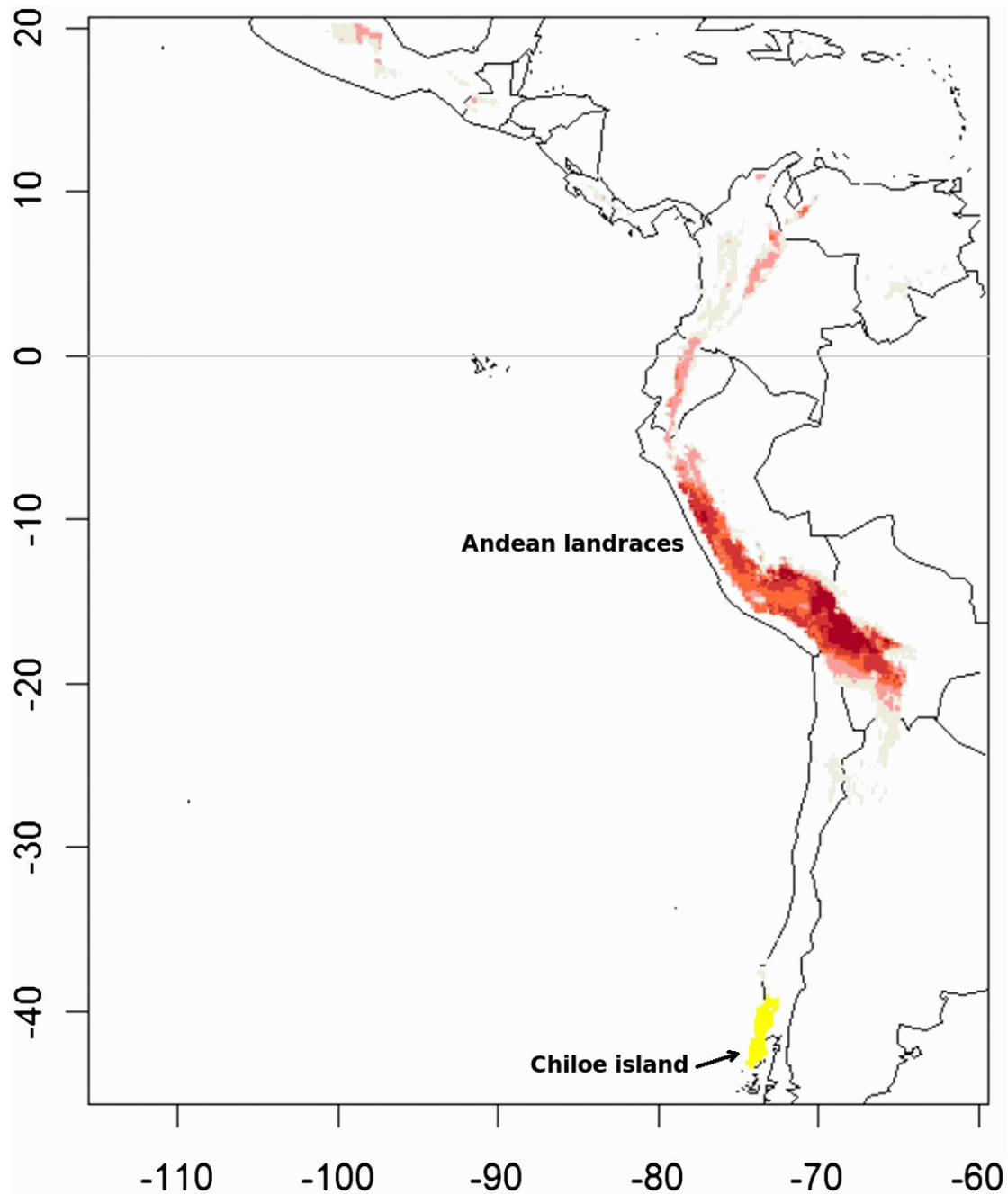
#### Diversity of potatoes

- All species from Petota section may form tubers
- The biggest yield is from tetraploid forms ( $2n = 48$ ) growing in Central Andes and island Chiloe

#### Potatoes of Ecuador



Richness of potato landraces (from Spooner et al., 2010)



### Agriculture of potatoes

- The best is extremely simple agriculture plus high energetic yield
- Planting is from potato buds, not from seeds
- Critical stage of cultivation is “hilling”, increasing the soil level around stems
- Harvesting is still not mechanized well
- Storage requires more stable conditions than seed storage

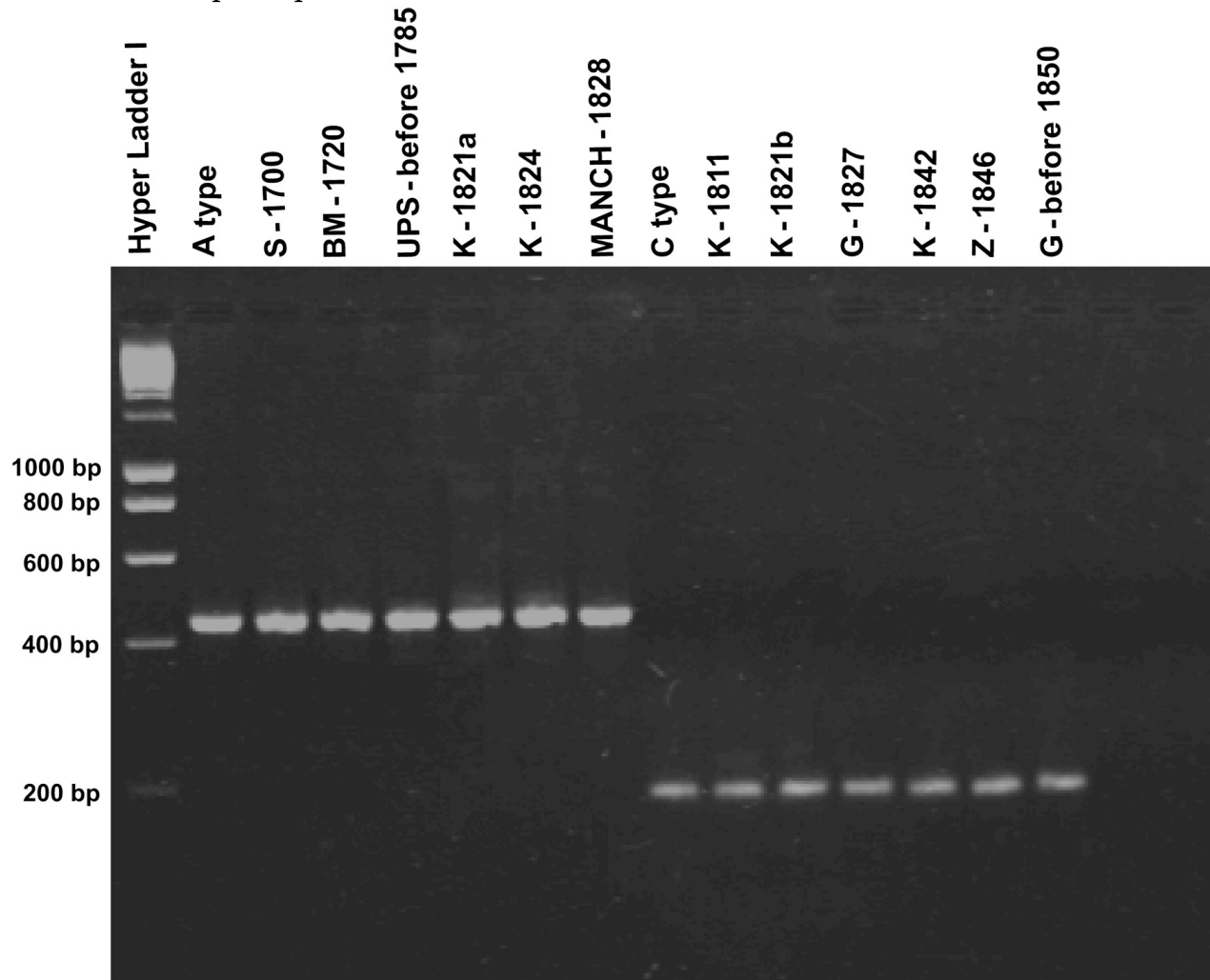
### History of potatoes

- Domesticated around 3,000 BC and together with quinoa became the main food of Inca empire



- Initially, used mostly as a freeze-dry “chunjo”
- Is known in Europe since 1601
- In XVIII century, was forcedly introduced into culture by many European monarchs and then became widely adopted
- Now, the main producers are China, Russia, India and U.S.

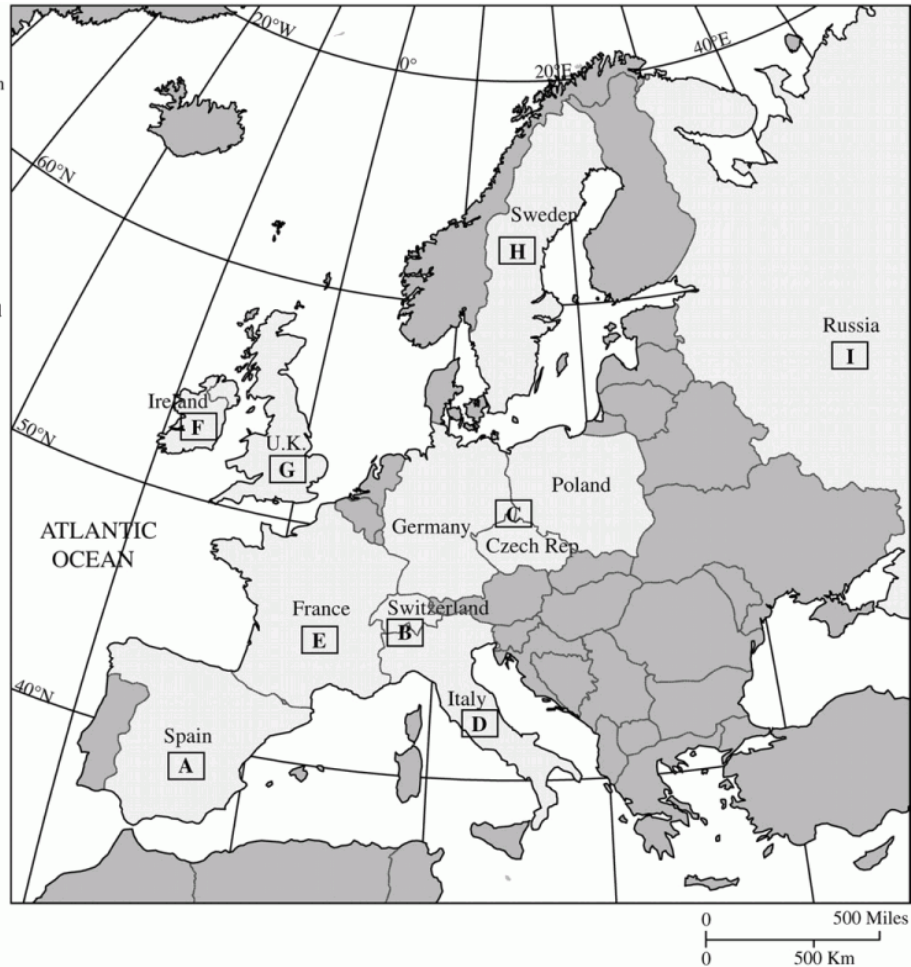
#### DNA test of European potato cultivars



Amplified PCR products of the plastid trnV-UAC/ndhC intergenic spacer region of 12 pre-1850 *Solanum tuberosum* specimens (Ames & Spooner, 2008)

#### Main dates of potato introduction (from Ames & Spooner, 2008)

- A. **1567.** Potato first documented in Europe in the Canary Islands (not shown, Spanish territory 1700 km SW of Madrid). **1573.** First record of potato used for human consumption in continental Spain.
- B. **1596.** First botanical description of the potato by Gaspar Bauhin.
- C. **1601.** Potatoes were cultivated in Prussia. **1771.** A famine stimulated potato cultivation.
- D. **1601.** Potatoes were cultivated in a few gardens. **1770.** Residents of Naples refused to eat potatoes during a famine.
- E. **~1600.** Potato cultivation established in eastern France. **1749.** Potato considered “exotic.” **1761.** Public demonstrations that potatoes were a safe food. **1771.** Parmentier effectively promoted potatoes as a safe food. **1814.** A collection of ~120 potato varieties were gathered by the National Society of Agriculture.
- F. **1640.** Potato documented as a field crop.
- G. **1662.** Potato became an object of importance, and the Royal Society recommended planting potatoes to prevent famine. **1760.** Potatoes gained wider acceptance as a field crop in Scotland. **1830.** Potatoes commonly cultivated in England.
- H. **1764.** A royal edict issued to encourage potato cultivation.
- I. **1850.** Nicholas I forced people to cultivate potatoes.



## Great Irish famine and *Phytophthora infestans*

- Potato occurred to be susceptible for several dangerous pathogens, e.g., potato blight “fungus” (*Phytophthora infestans*)
- Pandemic of potato blight covered Europe in the middle of XIX century (1845–1852), when potato became the main food in many northern European countries including Ireland
- In Ireland, it resulted in 1 million deaths and decreasing of population to 25% due to emigration

## Potato blight, *Phytophthora infestans*



One of Irish famine monuments



### Colorado beetle (*Leptinotarsa decemlineata*)

- One of the most dramatical example of American invasive species in Europe
- In Colorado Rocky Mountains, these beetles were feeding on *Solanum rostratum* plants but not on potato
- During World War I and then especially World War II, it became spreading across all Western Europe and then eastward
- Distribution is now covered all North Hemisphere (except China)

### Colorado potato beetle...





... and its first host, *Solanum rostratum*





## 17.2 Sweet potato, *Ipomoea batatas*

### Sweet potato, *Ipomoea batatas*

- Belongs to morning glory genus *Ipomoea* from Convolvulaceae family
- Cultivated for thickened secondary roots (tuberous roots, not tubers!)
- Contain 12% of starch, 5% of sugars, little proteins and almost no fat
- Rich of vitamins, especially vitamin A precursor beta-carotene

### Sweet potato morphology

- Herbaceous vine, perennial plant cultivated as annual
- Tuberous roots are large, up to 25 kg
- Reproduction is both from seeds and vegetative, from root and stem parts (grafts)
- Large, trumpeting, insect-pollinated flowers

### *Ipomoea batatas*, sweet potato





## Sweet potato agriculture

- Pure tropical culture, does not tolerate frost
- Requires short days, full sun, light soil
- Planting as grafts, this increases the number and weight of tuberous roots (subsidiary roots)
- Green part is used as a forage for animals

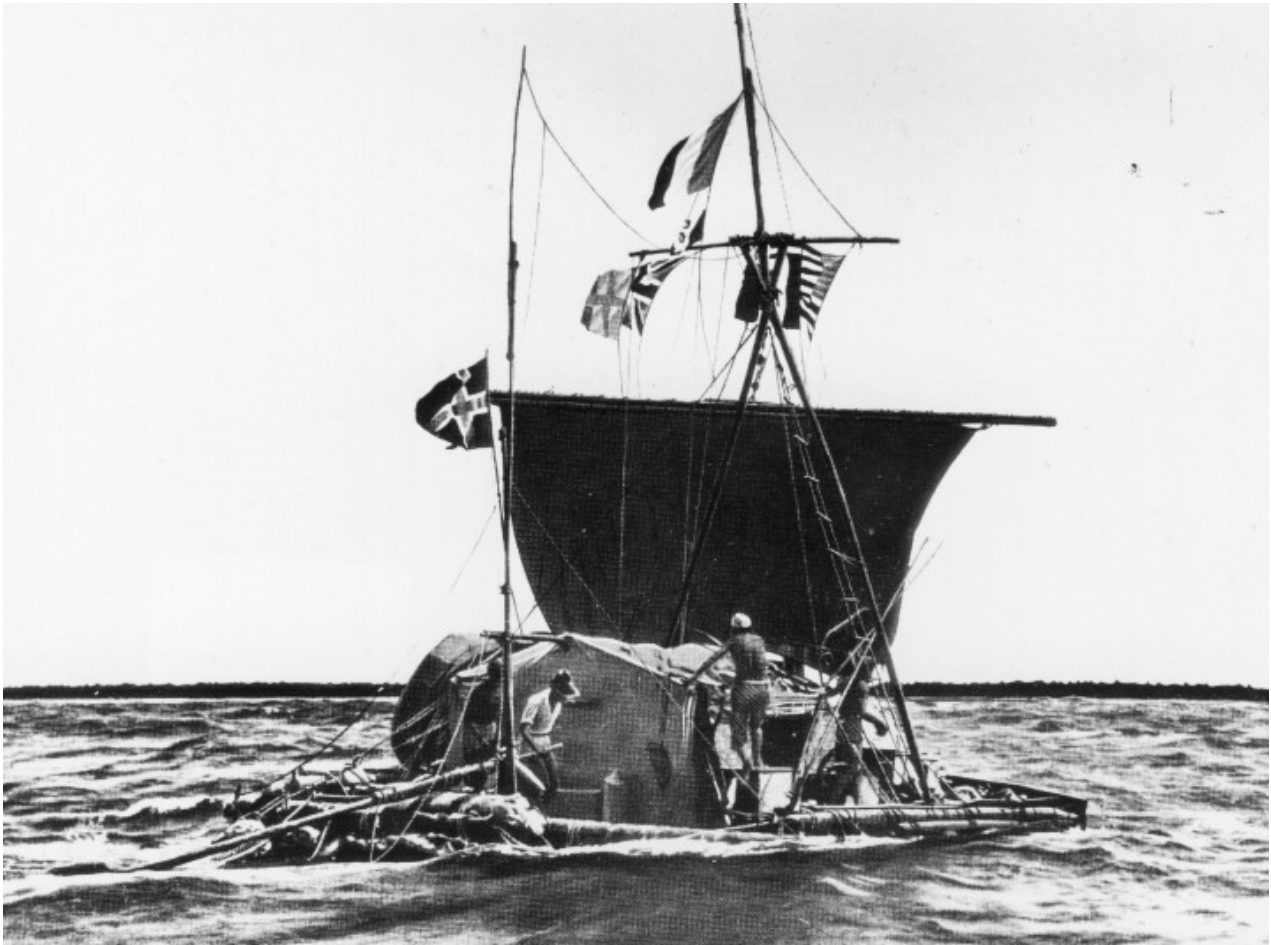
## Planting of sweet potato



## History of sweet potato

- Domesticated in Central America almost 3,000 BC and spread to Polynesia before European colonization
- In Polynesia, it is called the “kumara”, remarkably similar to the Quechua “kumar” in Peru: that is one of reasons for Thor Heyerdahl Kon-Tiki expedition
- Now two main producers are China and Nigeria

Kot-Tiki raft, 1947



### 17.3 Cassava, *Manihot esculenta*

Cassava, manioc, *Manihot esculenta*

- Belongs to the tree genus *Manihot* from spurge family Euphorbiaceae
- Third largest source of carbohydrates in the world
- It is a shrub cultivated as annual (!)
- Secondary roots (not stems!) are thickening and form tuberous parts

In Spanish, called “yuca” (do not mix with aloe-like *Yucca* plant).

**Cassava plantation**





### Cassava features

- Tuberous roots have high amount of dry mass (30%), high in starch, phosphorous and vitamin C but poor in proteins and essential amino acids
- **Toxic**, contain cyanogenic compounds which are liberating hydrogen cyanide (HCN). Consequently, should be pressed, soaked, cooked or fermented before use. Without preparation caused a *konzo* disease.
- Harvesting is manual; roots are deteriorated fast and should be processed as soon as possible

### Cassava preparation: peeling





Cassava preparation: grinding





Cassava preparation: pressing



Cassava preparation: drying



### Cassava history

- Domesticated in Brazil around 6,000 BC
- Went to Africa with Portuguese trades and then to south-west Asia
- Now, Nigeria and Thailand are biggest producers

## 17.4 Yam (tropical yam), *Dioscorea* spp.

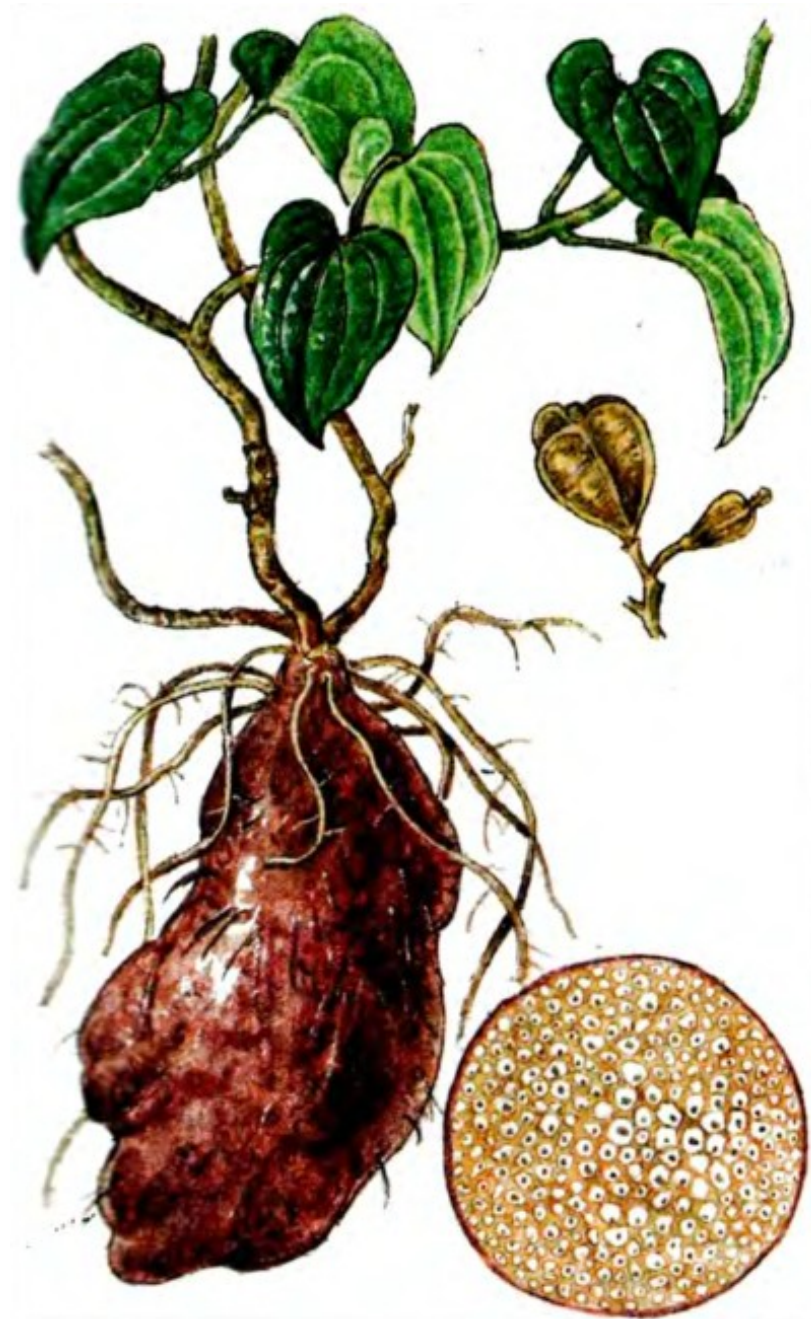
### Yam, *Dioscorea* spp.

- Several species of large genus *Dioscorea* and Dioscoreaceae family
- Cultivated for tubers (morphologically similar to potato tubers)
- Frequently used as a flour
- Could be stored up to half-year, even in tropical climate

Sweet potato is sometimes called “yam” in U.S.



## Yam, *Dioscorea*



### Yam features

- Tubers could be huge: up to 2,5 m and 70 kg
- Contain starch, significant amounts of vitamin C, and several microelements
- Hilling is an important stage of cultivation
- Long vegetation period (up to 1 year)
- Due to the size of tubers, harvesting is only manual



## Yam plantation



## Yam history

- Three most cultivated species: *Dioscorea rotundata*, yellow yam of Africa; *D. alata*, water yam of Polynesia; and *D. opposita*, Chinese yam
- These species were separately domesticated, most probably prehistorically
- During potato pandemic, *D. alata* cultivation started in Europe, still cultivated in France
- Now the biggest producer is Nigeria

## Water yam of Tonga



## 17.5 Taro

Taro, *Colocasia esculenta* and *Xanthosoma sagittifolium*

- Belong to arum family, Araceae
- African and South American origin, respectively
- Large semi-aquatic herbs with thickened underground stem (rhizome)
- Rhizome is inedible because of calcium oxalate which must be removed by cooking

*Colocasia* is “malanga” in Puerto-Rico whereas *Xanthosoma* is “yautia”



*Colocasia esculenta*



*Xanthosoma sagittifolium*



Taro harvesting





Walmart vegetables in Puerto Rico



## Summary

- **Starch-containing plants** are accumulating starch or inulin in underground parts
- Sweet potatoes and cassava (manioc) are two largest starch sources after potato
- Multiple unrelated tuber starch-bearing species grow in Andes

## For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)
- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

## Outline

# 18 Starch-containing plants

## 18.1 Lesser starch-containing plants

### Bread tree, *Artocarpus integer*

- Large tree of mulberry family, Moraceae
- Polynesian origin
- Has a compound “fruit”—ripe inflorescence
- A common product is a cooked or **fermented** breadfruit mash
- It is normally kept for the very long time as a sour dough which helps for Polynesian traditional life style, involving long travels from island to island.

### Breadfruit





Breadfruit fermentation place, Marshall islands



## Summary

- **Starch-containing plants** are accumulating starch or inulin in underground parts
- Sweet potatoes and cassava (manioc) are two largest starch sources after potato

- Multiple unrelated tuber starch-bearing species grow in Andes

## For Further Reading

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## Outline

# 19 Starch-containing plants

## 19.1 Lesser starch-containing plants

Sago palm, *Metroxylon saghu*

- Belongs to palm family, Palmae
- Tree of Indonesian origin
- Stem (!) is used for starch (sago) production

Sago palm





Sago harvesting



Sago filtering





### Andean starch tuber plants

- Oca, *Oxalis tuberosus*, from Oxalidaceae, wood sorrel family
- Ulluco, *Ullucus tuberosus*, from Basellaceae family
- Mashua, *Tropaeolum tuberosum* from Tropaeolaceae, nasturtium family

### Oca, *Oxalis tuberosus*





Ulluco, *Ullucus tuberosus*



Mashua, *Tropaeolum tuberosum*



## 19.2 Starch plants of native use

### Arrowhead, *Sagittaria latifolia*

- “Pshitola” (Dakota), “mujotabuk” (Ojibwe)
- Aquatic plant from Alismataceae family
- Rhizomes are used as a source of starch

### Arrowhead, *Sagittaria latifolia*





**Quamash (*Camassia quamash*)**

- Famous “Quamash”, important food source of Native Americans in the West
- Belongs to lily family, Liliaceae
- Bulbs are edible and highly nutritious

**Quamash, *Camassia quamash***





Quamash roots



## Summary

- **Starch-containing plants** are accumulating starch or inulin in their underground parts
- Sweet potatoes and cassava (manioc) are two largest starch sources after potato
- Multiple unrelated tuber starch-bearing species grow in Andes

## For Further Reading

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- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

## Outline

## 20 Starch-containing plants

### 20.1 Starch plants of native use

Quamash (*Camassia quamash*)

- Famous “Quamash”, important food source of Native Americans in the West
- Belongs to lily family, Liliaceae
- Bulbs are edible and highly nutritious

Quamash, *Camassia quamash*



Quamash roots





**Potato bean, groundnut, *Apios americana***

- “Mdo” in Dakota language; belongs to legume family (Leguminosae)
- Grow across all eastern part of U.S.
- Used by Native Americans as a main starch source, tubers also contain significant amounts of proteins; beans are also edible

**Potato bean, *Apios americana***



Prairie turnip, breadroot, *Psoralea esculenta*

- “Tiksi” in Dakota language
- Common plant of North Dakota
- Thick main root is edible after cooking or making flour

Breadroot, *Psoralea esculenta*





## 20.2 Inulin plants

### Jerusalem artichoke, *Helianthus tuberosus*

- Belongs to Compositae (sunflower) family
- Tubers are rich of inulin, fructose polymer, useful dietary fiber
- Plant was used by eastern Indian tribes and now spread to Eurasia

### Jerusalem artichoke





Jerusalem artichoke tubers



### Some other inulin plants

- Common chicory, or *Cichorium intybus* from the same family Compositae; this European plant became invasive in North America
- Chicory is cultivated sporadically as vegetable and as a source of chicory drink—coffee supplement; 68% of inulin in dry weight
- Dandelion, *Taraxacum officinale* is again an invasive plant; inulin-containing root is edible after cooking
- Yacon (*Smallanthus sonchifolius*) is cultivated in Andes
- Many other Compositae (e.g., thistles) also have edible roots rich of inulin

### Chichory



One of thistles, *Arctium*





### 20.3 Starch plants from sedge family: starch + silicon

Water chestnut, *Eleocharis dulcis*, Cyperaceae, China

- Rich of dietary fibers, vitamins B, copper and manganese
- Cell walls contain phenolic compounds which are not damaged when boiling

Water chestnut



Chufa, *Cyperus esculentus*, Cyperaceae, Africa

- Tubers are rich of potassium, phosphorous and oils (20–36%!)
- Traditional food in Africa, also cultivated in Spain and California

Chufa





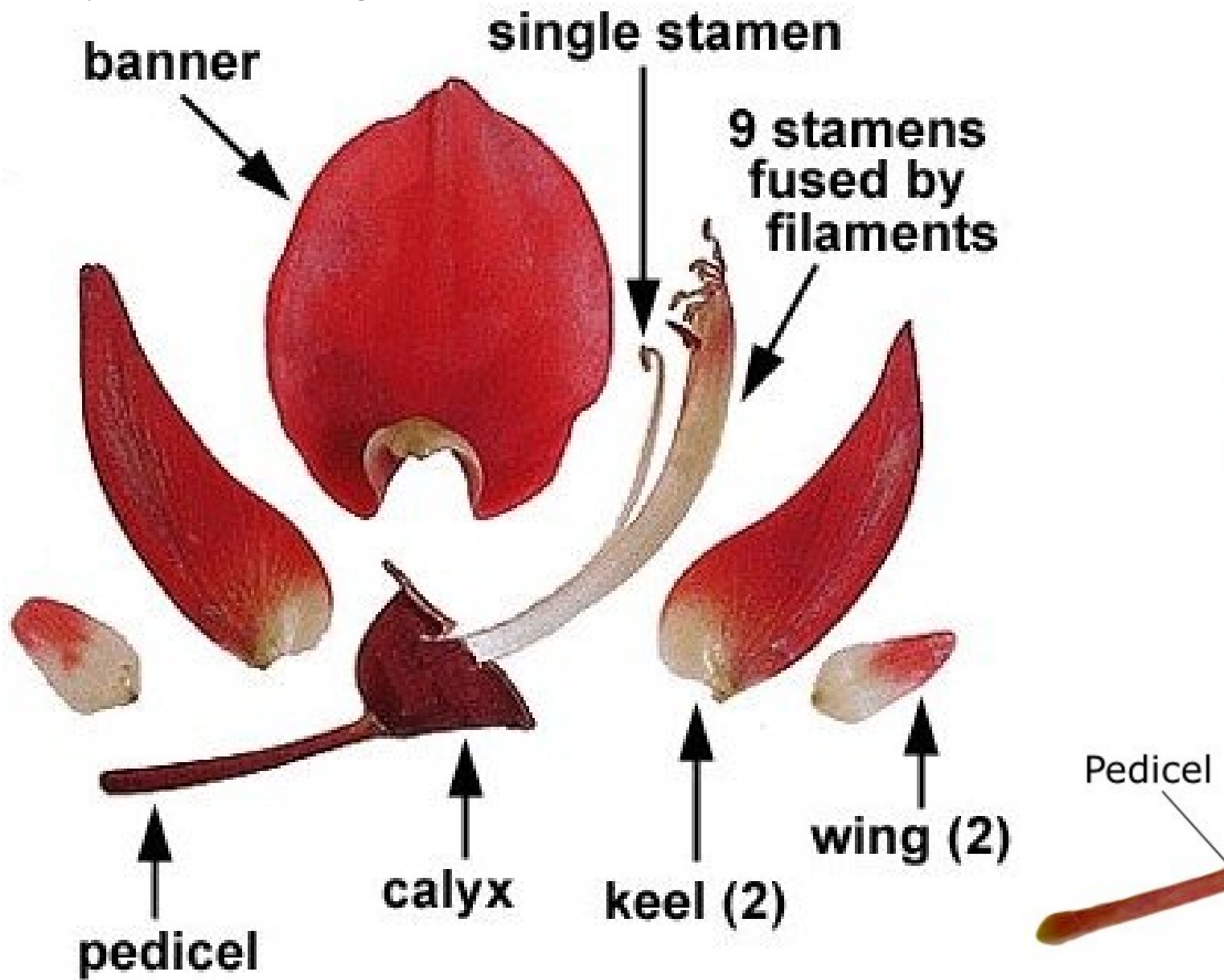
## 21 Legumes

### Main characteristics of legumes

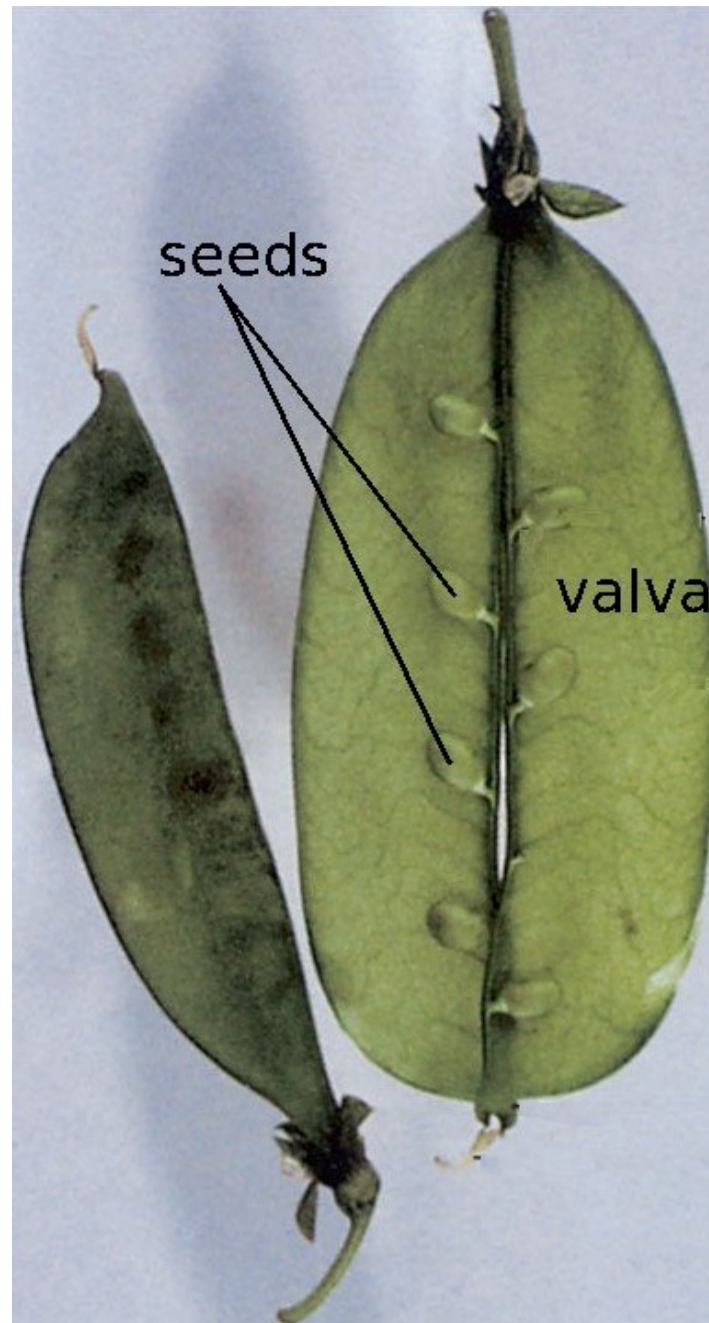
- One of the biggest plant families, more than 15,000 species
- Two most important characters: monosymmetric flowers with banner and keel; and monomeric legume fruit
- Nitrogen-fixing bacteria form root nodules (for cultivation, there are special *nitragines*)
- Consequently, all parts of legumes are rich of proteins, 2–4 times more than in cereals



Monosymmetric flower of legumes



Legume: the fruit of Leguminosae



Root nodules



## 21.1 Soya beans, soybeans, *Glycine max*

### Soya beans, *Glycine max*

- The most cultivated legume
- Seeds contain 42% of proteins including essential amino acids lysine, methionine and tryptophan; plus 20% of non-saturated oils
- Nearly universal culture: used as food, as technical culture, as oil culture and for the forage

### Soya flowers





### **Soya features**

- Cultivated mostly to the south from 50° latitude
- Nitrogen assimilation is slow at the beginning of season and reach the pike when plants start to flower
- Yield is  $\approx 2$  ton/hectare
- Main producer is United States, than Brazil

### **Soya agriculture**

- Requires warm, wet and shiny climates; tolerates small frosts
- Easily grow on different soils but needs crop rotation
- Relatively fast growing: 120–150 days
- The biggest problem is harvesting: early harvesting leads to decaying of seeds whereas late harvesting results in legume cracking

## Soya beans



### Soya history

- Prehistoric crop in East Asia
- Introduced in Europe and North America about the end of XVIII century
- In U.S., considered as technical and did not used for food until late 1920s

## 21.2 Beans (*Phaseolus vulgaris*)

### Beans (*Phaseolus vulgaris*)

- The second most cultivated legume

- “Beans” is the name of multiple cultivated legumes (more than 10 genera), but in strict sense, there are common beans, *Phaseolus vulgaris* and similar species
- Seeds are rich of carbohydrates and proteins
- Green legumes are also used as vegetables

### Beans features

- Herbaceous annual vines with deep roots
- High diversity of cultivars
- Beans should be cooked for at least 10 min at 100° C to destroy weakly poisonous *phytohaemagglutinins*

### Beans





## Diversity of common beans



- Navy beans (*Phaseolus vulgaris*, multiple cultivars)
- Lima beans (*Phaseolus lunatus*)
- kidney beans (*Phaseolus vulgaris* cv. 'Red Kidney')
- Pinto beans (*Phaseolus vulgaris* cv. 'Pinto')
- and many others...

## Beans agriculture

- Extremely heat tolerant, requires average watering
- Does not grow well in colder climates
- Require short days; soil type is not critical
- Often cultivated inside mixed crops (with corn, rice, safflower)

## Beans history

- Native culture of Central America and Mexico; important plant for Aztec civilization
- Spread around the world in XIX century
- Top producers now are Brazil and India

## 21.3 Pea (*Pisum sativum*)

### Pea (*Pisum sativum*)

- Old culture of Old World, one of most hardy legumes
- Food and forage plant
- Seeds are high of carbohydrates (14%, and 1/3 of them are sugars) and proteins (5%)

### Pea flowers



### Pea features

- Annual herb which is able to climb up to 2 m with tendrils

- Comparing with other legumes, has an extremely short vegetation period, from 65 days (!)
- The northern line of cultivation is 68° latitude
- Long-day culture, also requires wet soils

### Pea history

- Domesticated prehistorically in West Asia; wild landraces of same species are still exist
- Spread to both Western Europe and Eastern Asia (common culture in Japan)
- Self-pollinated, and became a famous model plant of first genetic experiments made by Gregor Mendel

## 21.4 Lentils, *Lens culinaris*

### Lentils (*Lens culinaris*)

- One of the oldest cultivated plants, has been part of human diet since Neolithic times
- Rich of proteins (26%) and especially carbohydrates (60%)

### Lentil





### **Lentils features**

- Annual herbaceous vine up to 1 m high
- Less hardy than pea, requires warm season, vegetation period is often more than 100 days
- Long-day plant, drought tolerant (this is rare among cultivated legumes)
- Has relatively low yield (0.8 ton/hectare)

### **Lentils history**

- Was domesticated in West Asia even before first civilizations appear
- Mentioned in Old Testament since it was a common food for Palestinian nations

- The word “lens” originated from Latin name of lentils
- Biggest producers are now Canada and India

### Red and brown lentils



## 21.5 Chickpea (*Cicer arietinum*)

### Chickpea (*Cicer arietinum*)

- One of primary Indian food plants
- Composition and yield is similar to lentils ( $\approx 23\%$  proteins and  $64\%$  carbohydrates, 0.8 ton/hectare)
- Has big seeds, requiring more boiling time than other legumes (up to 2 hours)
- Green parts are not edible as forage

### Chickpea





### **Chickpea features**

- Drought tolerant and therefore cultivated in arid climates
- Does not require specific soils
- Prefer long-days: does not go far into tropics; biggest producers are India, Pakistan and Turkey

**Chana masala: Indian cousine**





### Some other legumes

- Pigeon pea (*Cajanus cajan*) perennial legume, originated in India
- Hyacinth bean (*Lablab purpureus*) has the African origin, it is frequently grown also as ornamental

### Summary

- **Starch-containing plants** are accumulating starch or inulin in their underground parts
- Legumes are rich of proteins including essential amino-acids
- They mostly require humid climates and do not need specific soils
- Crop rotation is needed for most of legume cultures

### For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)

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## Outline

# 22 Centers of cultivated plants origin

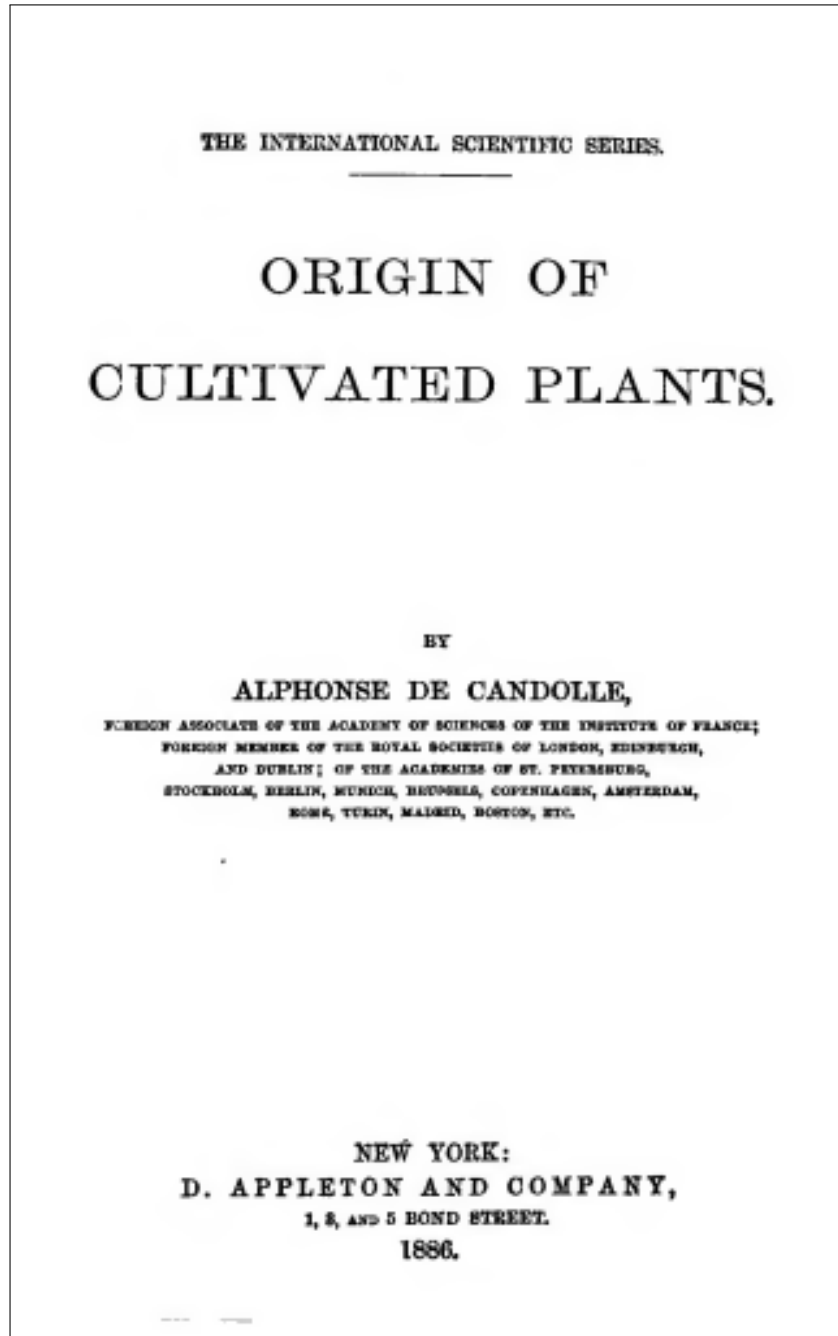
## Why knowing centers of origin is important

- Tracing history of civilizations alongside with history of plant cultivation
- Historical discoveries
- New landraces and wild relatives useful for selection

## Initial hypotheses: De Candolle (1882)

- Mentioned that distribution of ancient cultivated plants was very unequal
- Found three centers of plant origin: China, West Asia/Egypt and tropical Asia

## De Candolle's "Origin"



### Nikolai Vavilov work (1926)

- On the 5th International Genetics Congress, he presented his new classification of centers based on field and collection research
- Differential method: studying density of distribution on a level of varieties. Places where biggest densities were intersected become “centers candidates”
- In 1930s, he establishes “ecological passports” of territories which show ecologic, economic and geographic traits

### Vavilov’s centers (1926)

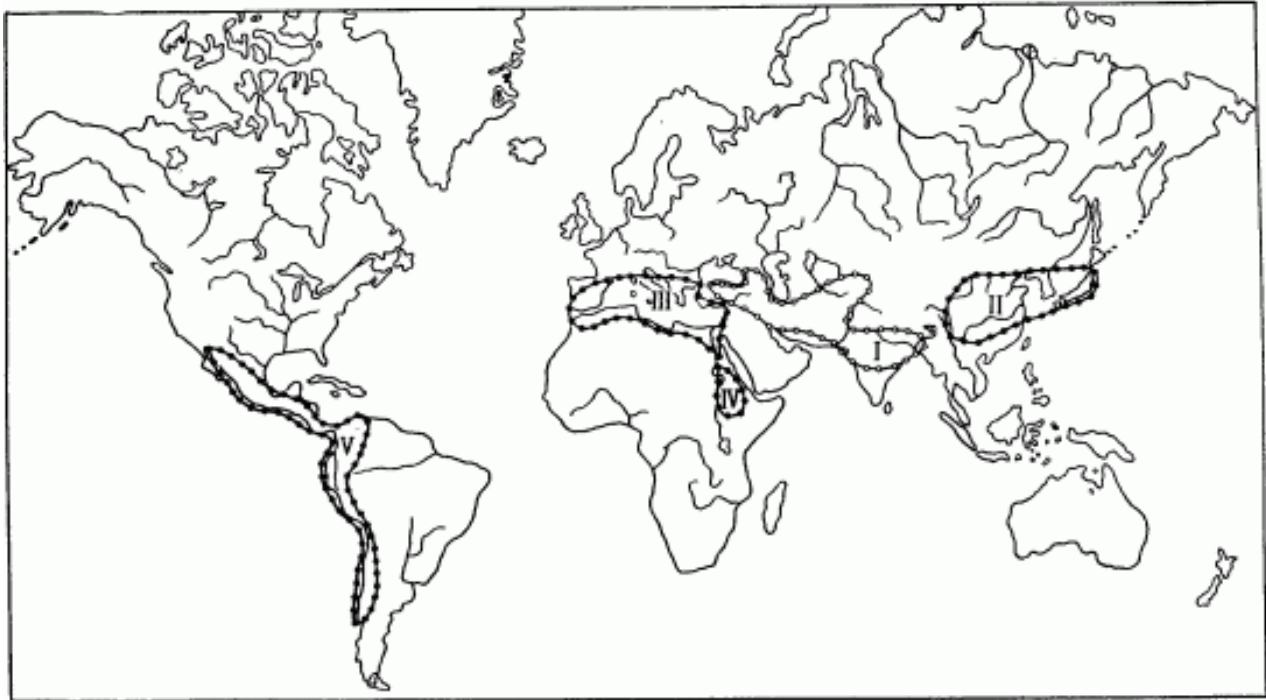
In 1926, he designated five centers of origin:



1. India
2. China
3. Mediterranean region
4. Ethiopia
5. South and Central America

Later, he added some (Central Asia) and split some of them

#### **Five Vavilov's centers**



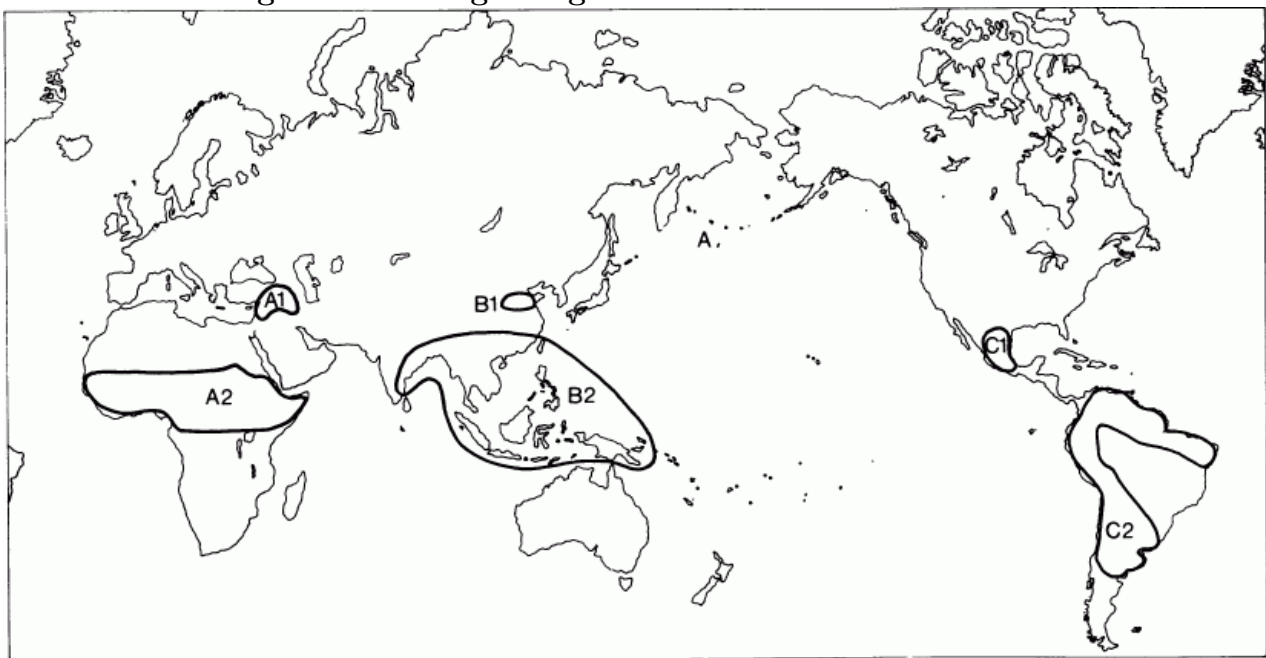
#### **More recent hypotheses**

- Darlington (1952): several American centers, twelve centers in total
- Harlan (1971): “centers of agricultural beginnings”: only six
- Zhukovskij (1965–1982): 12 “megacenters” (regions). All Vavilov’s centers listed, plus several which do not produce substantial amounts of cultivated plants but still separate

#### **Darlington's centers**



Harlan's centers of agricultural beginnings



Centers of origin from Zhukovskij

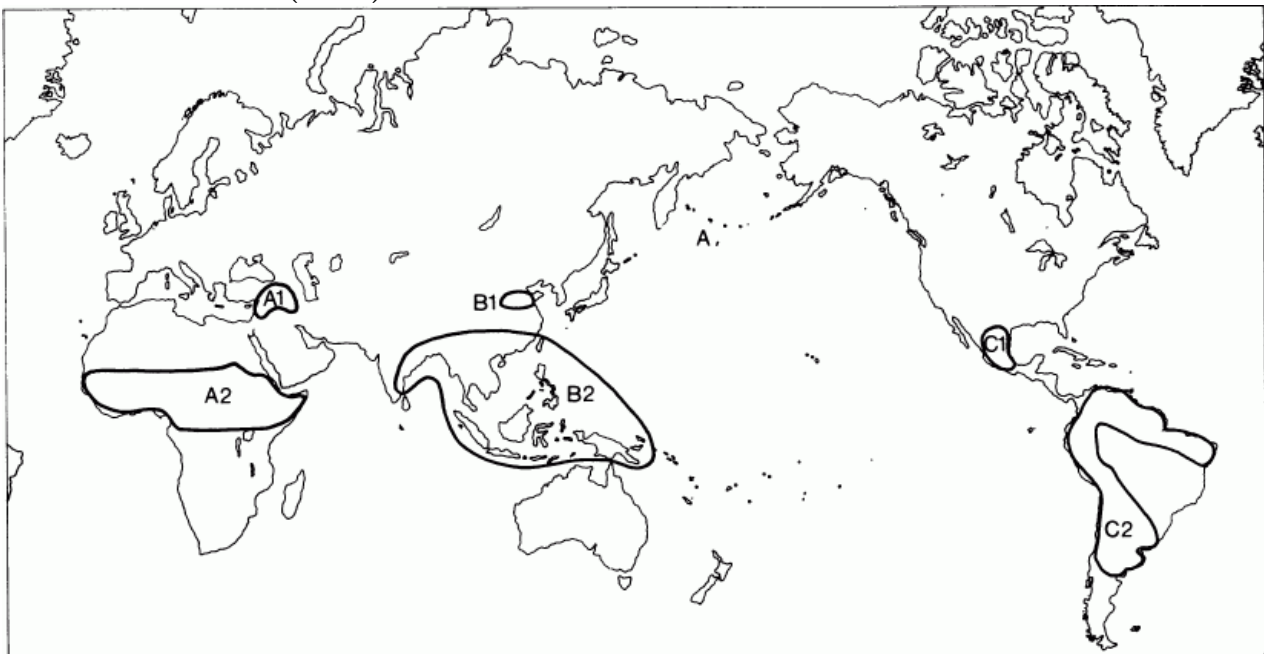
- China
- Indochina—Indonesia
- Australia—New Zealand
- India
- Central Asia
- West Asia

- Mediterranean
- Africa
- Europe—Siberia
- Central America
- Bolivia—Peru—Chile
- North America

#### Zhukovskij's regions (centers)



#### We will follow Harlan (1971)





### **West Asian center (A1)**

- Plants relatively small, stiff stems and leaves, drought-tolerant
- Some wheats, two-rowed barley, oats, lentils
- Ancient Egypt and Mesopotamia

### **Indian center (B2)**

- Xerophytes\*, small leaves, rapid development and filling-out of seeds, small seeds, extremely susceptible to European fungal and bacterial diseases
- Some wheats, six-rowed barley, finger millet, chickpea
- Ancient Indus Valley Civilization

### **African/Ethiopian center (A2)**

- Adapted to poor soils, starting to grow in the beginning or in the end of rain season
- Fonio, tef, sorghum, pearl millet
- Ancient African civilizations: Aksum, Yoruba, Benin

### **China center (B1)**

- Mesophytes and even hydrophytes, short development, small and medium-sized seeds, relatively big leaves
- Rice, soybeans
- Ancient Chinese kingdoms

### **Central American center (C1)**

- Xerophytes and mesophytes, slow growing, big seeds, drought- and hot-tolerant
- Corn, common bean, sweet potatoes
- Ancient Aztec and Mayan empires

### **South American center (C2)**

- Mesophytes, many are tolerant to low temperatures, big leaves, developed underground parts
- Cassava, potatoes, oca etc.
- Ancient Andean civilization

## 23 Sugar plants

### 23.1 Sugars

#### Sugars and their role

- Mono- and polysaccharides
- Glucose, fructose, sucrose, cellobiose
- Starch (amylose + amylopectin) and glycogen

#### Sugars and civilizations (speculation!)

- High level of glucose uptake by nervous cells
- Increasing use of sugars in human history
- “Unsuccessful” civilizations which did not find a reliable source of sugars

#### Ethanol

- Immediate product of yeast fermentation of glucose
- Pre-adaptation to alcohol from frugivores
- Bind to GABA (gamma-aminobutyric acid) receptors
- Converted into acetaldehyde (toxic!) by alcohol dehydrogenase and then into acetic acid by acetaldehyde dehydrogenase\*
- Asian flush and alcoholism are related to the genetic diversity of alcohol dehydrogenases

#### Downsides of sugars

- Obesity, because sugars are easily convert into fats
- Diabetes, because insulin cannot deal with large quantities of sugars
- Dental diseases, especially dental caries (caused by lactobacteria taking sugars for their growth)
- Multiple sweeteners have been developed to avoid side-effects of sugars: heterocyclic saccharine (in “Sweet’N Low”), amino acid derivative aspartame (in “Equal”), chlorine hexose sucralose (in “Splenda”, “Altern”). All are controversial.

#### Summary

- According to Harlan (1971), there are 6 centers (regions) of initial plant cultivation
- Sugar is highly used but controversial source of energy

#### For Further Reading

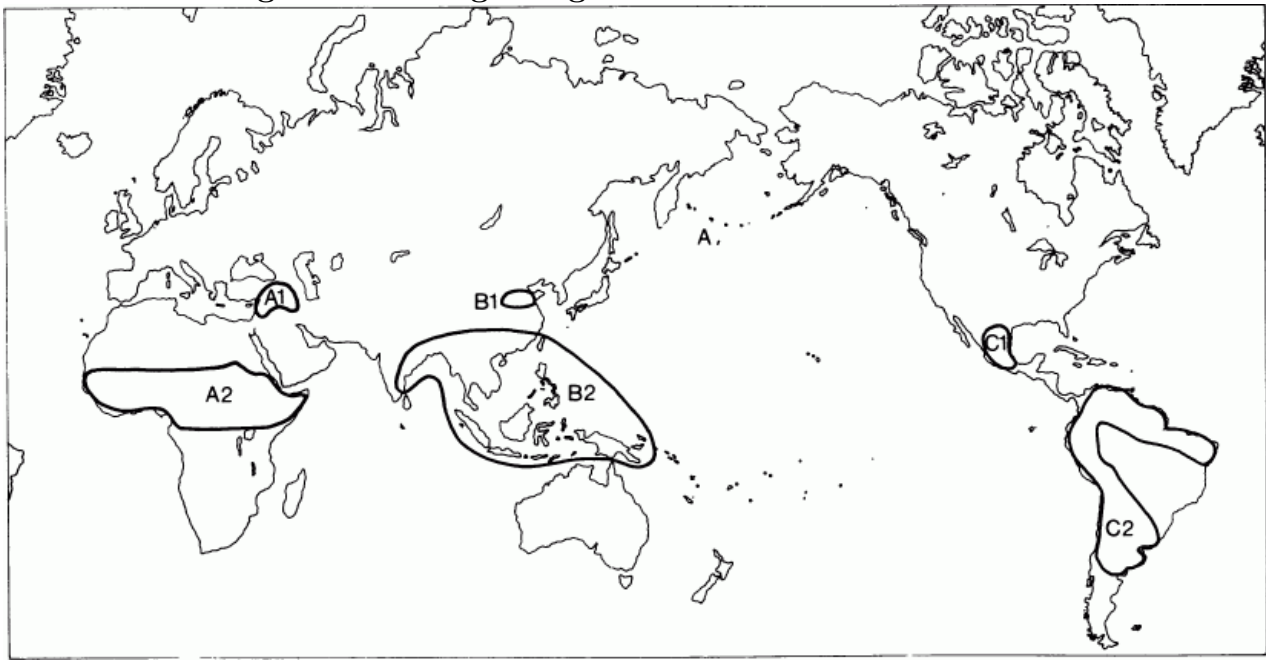
## References

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## Outline

## 24 Centers of cultivated plants origin

Harlan's centers of agricultural beginnings



## 25 Sugar plants

### 25.1 Sugars

#### Ethanol

- Immediate product of yeast fermentation of glucose
- Pre-adaptation to alcohol from frugivores
- Bind to GABA (gamma-aminobutyric acid) receptors
- Converted into acetaldehyde (toxic!) by alcohol dehydrogenase and then into acetic acid by acetaldehyde dehydrogenase
- “Asian flush” (result of acetaldehyde dehydrogenase deficiency) and alcoholism are related to the genetic diversity of alcohol dehydrogenases



## Downsides of sugars

- Obesity, because sugars are easily convert into fats
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- Multiple sweeteners have been developed to avoid side-effects of sugars: heterocyclic saccharine (in “Sweet’N Low”), amino acid derivative aspartame (in “Equal”), chlorine hexose sucralose (in “Splenda”, “Altern”). All are controversial.

## 25.2 Sweeteners

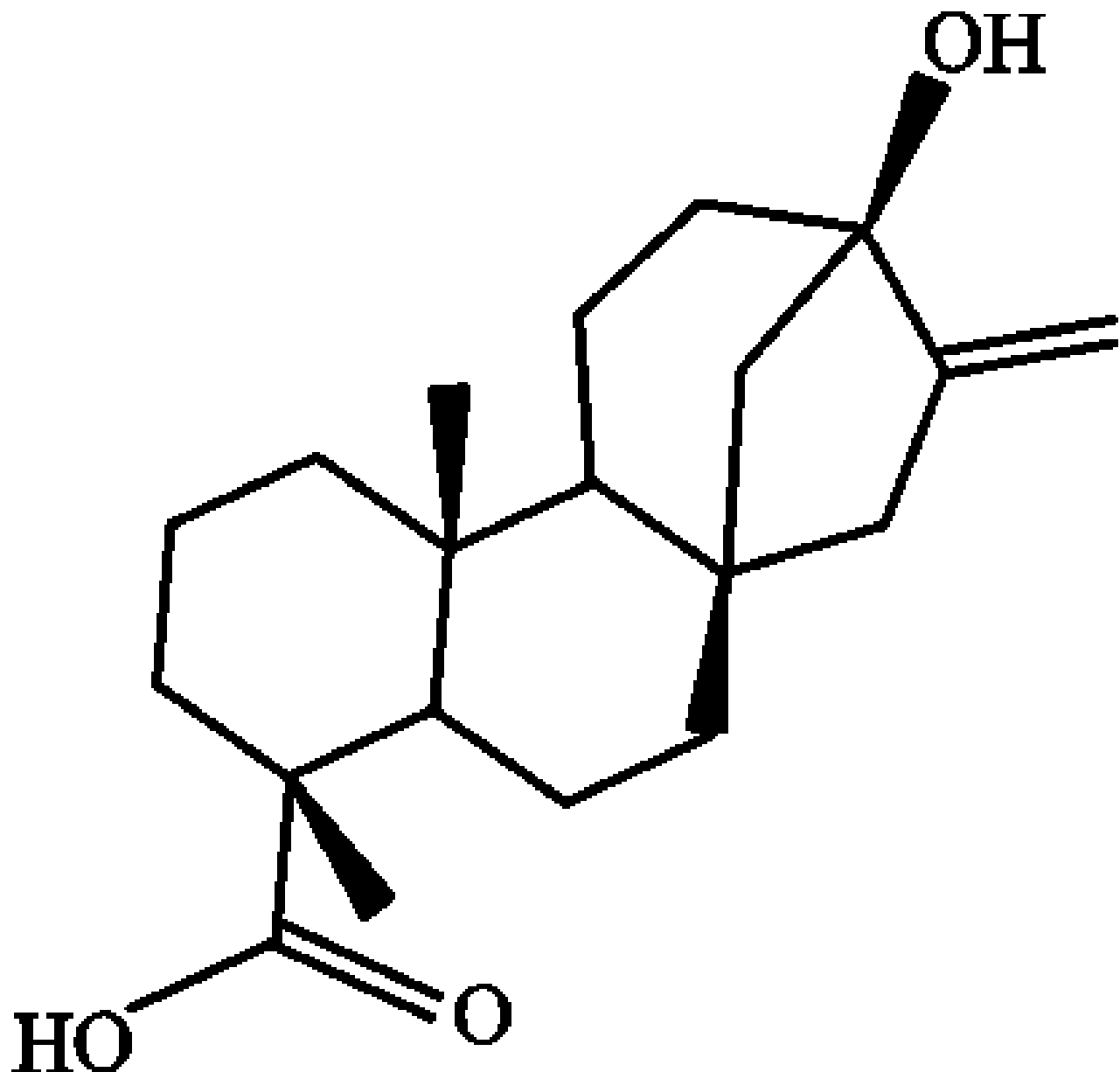
### *Stevia rebauldiana*, the natural sweetener

- Belongs to aster family, Compositae
- Originated in South America
- Leaves contain the group of sweet glycosides, derivatives of steviol
- They are 100–150 times sweeter than sucrose (on the weight concentration basis)
- Despite of multiple controversies (not approved in EU, banned in Norway and Singapore) used by Coca-Cola and PepsiCo in their “zero calories” drinks

### *Stevia* flowers



Steviol



#### Our native natural sweeteners

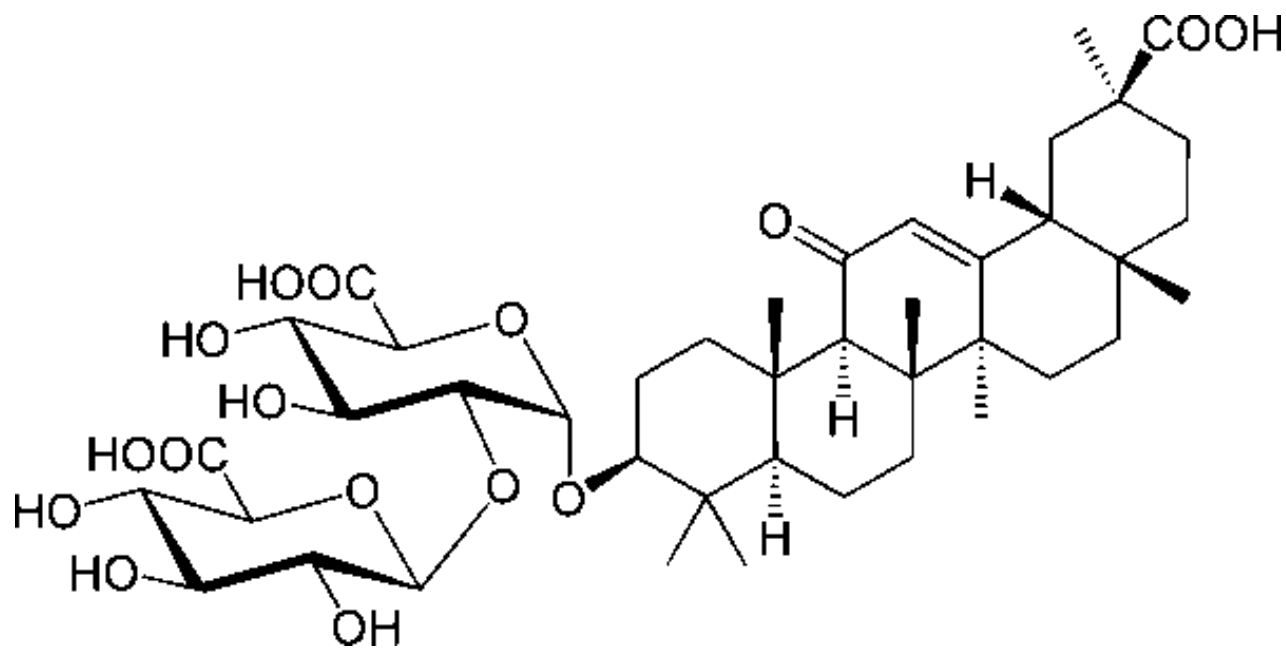
- North Dakotan wild licorice (*Glycyrrhiza lepidota*) belongs to legume family, Leguminosae
- Contains natural sweetener glycyrrhizin, about 50 time sweeter than sucrose
- Side-effects are hypertension and lowering of testosterone level in males

American licorice, *Glycyrrhiza lepidota*





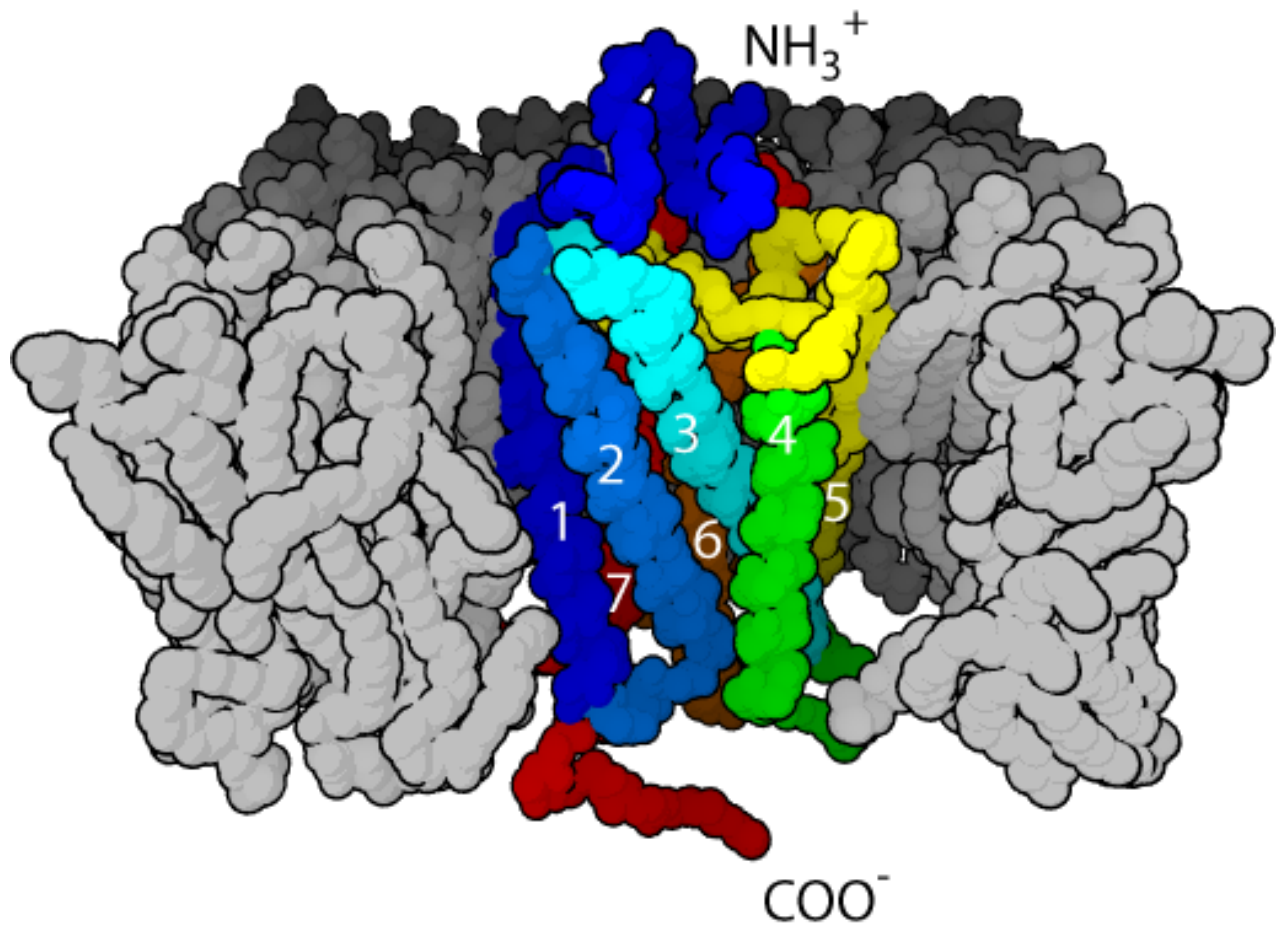
Glycyrrhizin



What is sweetness?

- Nature of sweetness is not yet fully discovered
- Probably due to specific Van der Waals forces occurring in variety of molecules
- These molecules have an effect on sweet receptors—large proteins from G protein-coupled receptors (GPCRs) group

**GPCR, sweetness receptor**



### Miracle fruit, *Synsepalum dulcificum*, the super-sweetener

- West African tree, belongs to tropical Sapotaceae family
- Berries convert sour tastes into sweet tastes (!), effect lasts for  $\approx 1$  hour
- The effect is due to glycoprotein miraculin which is binding to sweet receptors
- Cultivation is now starting in Florida, approval as food additive is pending—it is heat-resistant and may be used as a “sweetener”; there are genetically modified lettuce plants which produce miraculin

### Miracle fruit





Miraculin glycoprotein



### Other plants super-sweeteners

- Curculin from *Curculigo latifolia* (“lumbah-lumbah”), Malaysian herb from Hypoxidaceae family, has the same effect + it is also super-sweet by itself (500–2000 times sweeter on weight basis than sucrose).
- Thaumatin from *Thaumatococcus daniellii* (“miracle berry”), West African herb from Marantaceae, is 3000 times sweeter than sucrose.
- Monellin from *Dioscoreophyllum volkensii* (“serendipity berry”), West African Menispermaceae vine, is 800–2000 times sweeter than sucrose but only to Old World monkeys including humans.

### Lumbah-lumbah



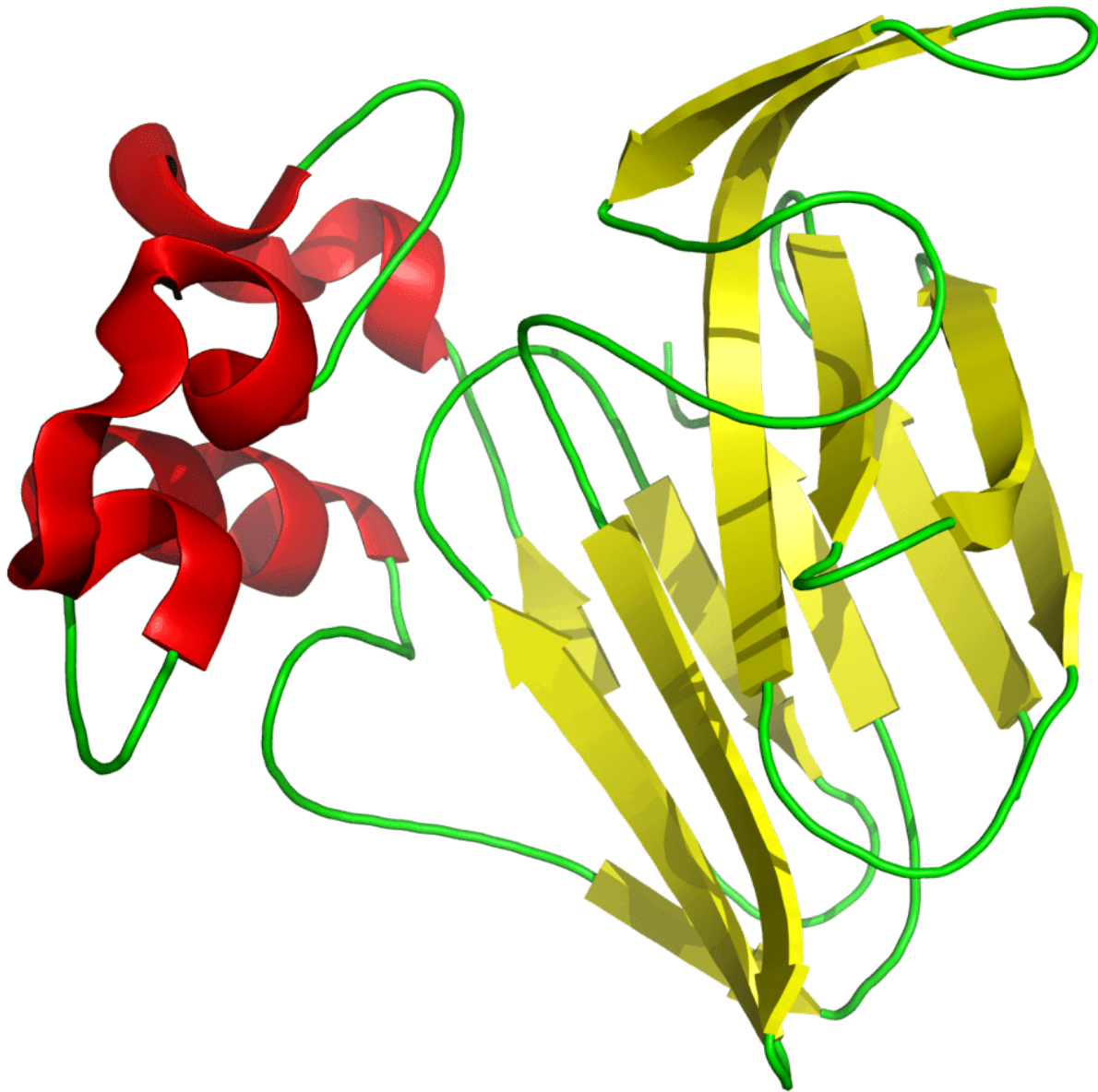


Miracle berry (not “miracle fruit”!)



Thaumatococcus, the most sweet protein





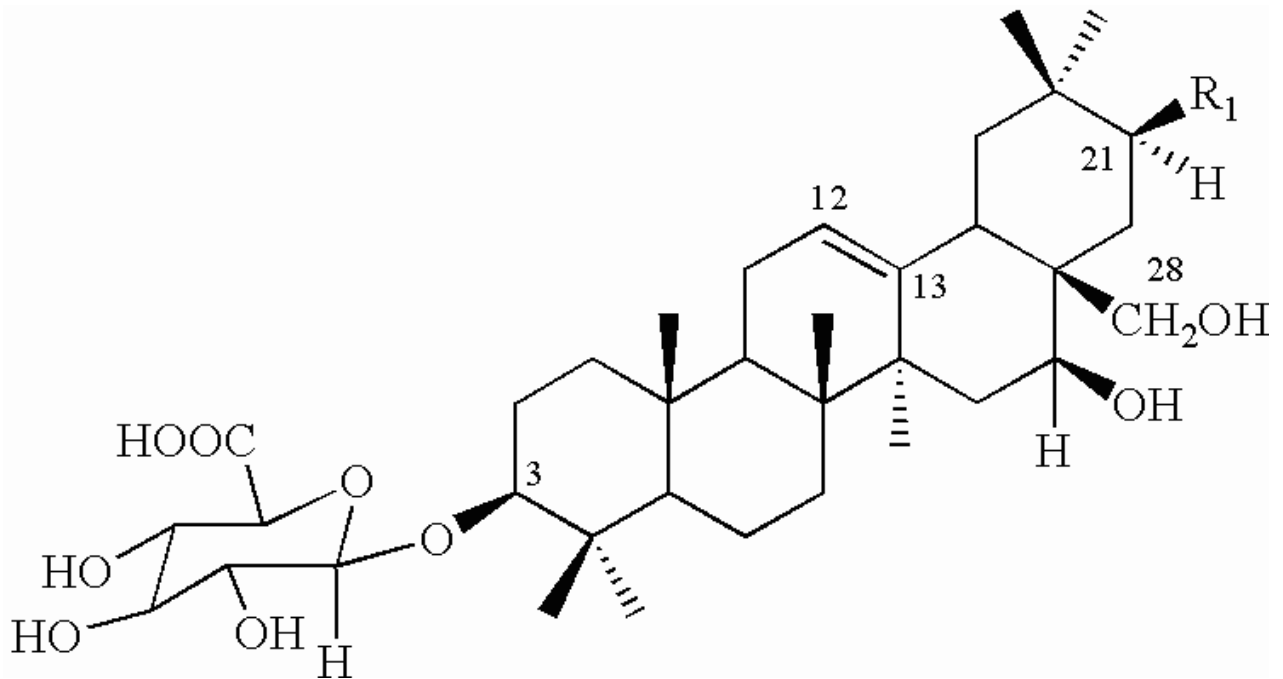
### Anti-sweeteners

- Several plants contain chemicals which are able to suppress sweet receptors
- Indian herbaceous vine *Gymnema sylvestris* from a dogbane family (Apocynaceae) contain gymnemic acids which suppress sweet taste for  $\approx 10$  min
- In addition, plant has an unrelated (?) effect in lowering blood sugars
- Used as a drug for curing Type 2 diabetes and different forms of metabolic disorders

### *Gymnema sylvestre*



## Gymnemic acid



## Summary

- Sugar is highly used but controversial source of energy

- Sweet taste still has undiscovered nature

## For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)
- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

## Outline

## 26 Sugar plants

### 26.1 Sugar cane

Sugar cane, *Saccharum officinarum*

- Belongs to grass family, Gramineae; it is a C<sub>4</sub> grass
- The oldest cultivated sugar plant
- Contains sugars in stem

Sugar cane





### **Sugar cane biology**

- Extremely tall grass, up to 6 m tall (!)
- Stem phloem\* juice contains 12–20% of sucrose in lower parts of stem
- Juice is pressed, filtrated, evaporated, centrifuged (to separate syrup from sugar crystals) and dried

### **Sugar cane agriculture**

- Grafted culture, it is not recommended to wait until flowering
- Short-day, sun-loving plant, optimal temperatures should be  $\geq 20^{\circ}\text{C}$

- Requires irrigation even in humid tropics (!) and significant amounts of phosphorous
- Vegetation period is up to 250 days

### **Sugar cane history**

- The culture started in Indian center, then moved to China and with Arabs—to Europe (Spain, 1150 AD)
- Arabs first invented white, filtrated sugar
- Went to Central and South America in XVI century (Europe needs sugar but it was not growing well there!).
- Now cultivated in tropical America, Africa and Asia (top producers are Brazil and India) but culture is declining under the pressure of competition with sugar beet
- Etymological dictionary says that:

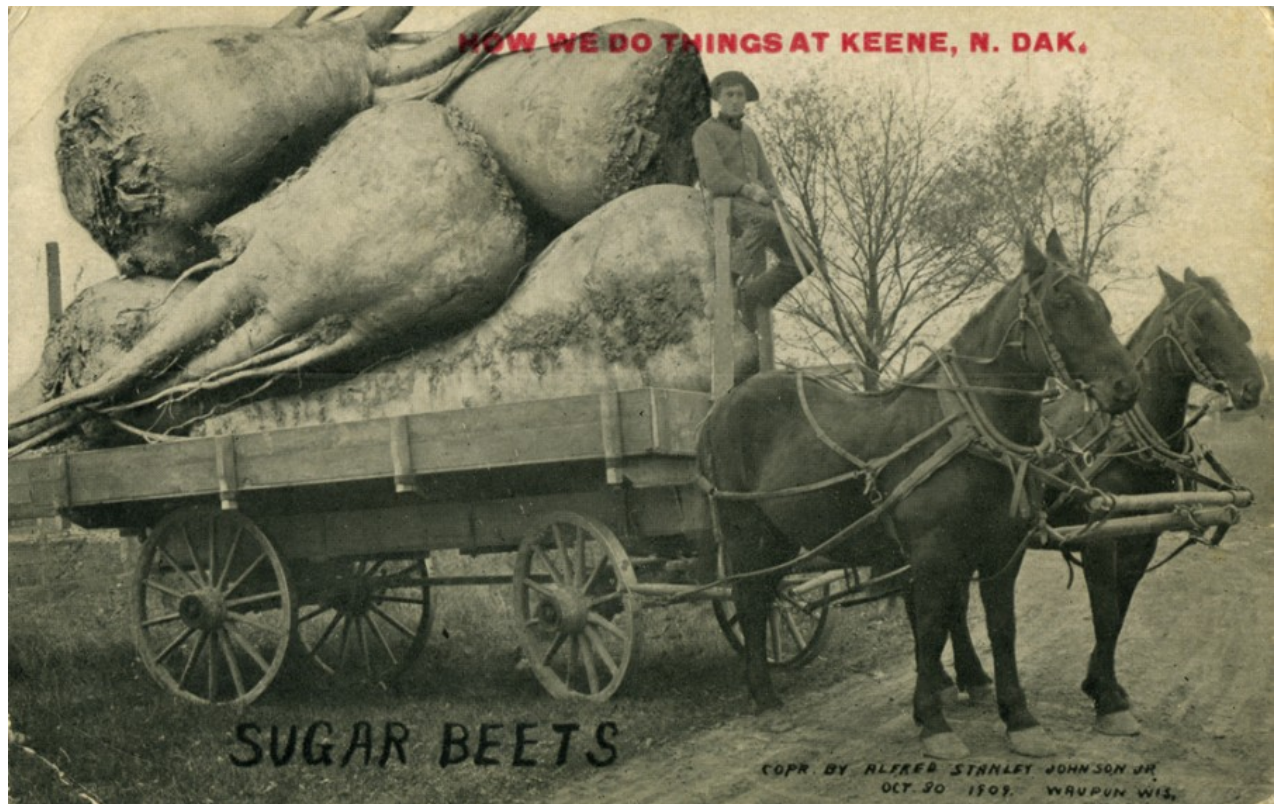
**sugar:** late 13c., from O.Fr. sucre “sugar” (12c.), from M.L. succarum, from Arabic sukkar, from Pers. shakar, from Sanskrit sharkara “ground or candied sugar,” originally “grit, gravel”

## **26.2 Sugar beet**

**Sugar beet, *Beta vulgaris* var. *saccharifera***

- Amaranth family, Amaranthaceae (or Chenopodiaceae in older classifications)
- Same species with vegetable beet
- Has been selected from leaf and root beets for only 300 years: one of the youngest cultures
- Root contains up to 20% of sucrose

**Sugar beet from North Dakota! (that’s a joke photo)**



### Sugar beet biology

- Biennial plant: first year with rosellate leaves, second year forms stem with non-showy flowers
- The “root” is actually intermediate structure between stem and root in strict sense—hypocotyl
- Has anomalous secondary growth (layers of tissues)
- Roots are “white”: do not contain betalain (red pigment which probably helps red beet to protect tissues from fungi and animals)

### Sugar beet agriculture

- Hardy plant: North Dakota is one of the leading states in sugar beet cultivation
- Yield is typically  $\approx 70$  ton/hectare (wet mass), and 12 ton/hectare (pure sugar): compare with  $\approx 100$  and  $\approx 10$  for sugar cane
- Some plants should be left for seeds (second year)
- Susceptible for weeds (needs herbicides)

### Sugar beet history

- In 1747, the sucrose content was discovered
- In 1810s, due to continental blockade of France, sugar mills were established across all Europe
- In XX century, sugar production was almost doubled
- Leading countries now are France, Germany and U.S.; one of biggest research centers is NDSU



## 26.3 Sugar maple

Sugar maple, *Acer saccharum*

- Tree from Sapindaceae (Aceraceae in older classifications) family
- Old semi-cultivated plant of eastern tribes of Native Americans
- Spring sap is the main source of sugar

Sugar maple



Native sugar-making



### Sugar maple features and history

- Sap contains 2–5 % of sucrose, the season starts in early spring and continues 4–8 weeks
- In total one tree could produce up to 50 liters of sap per season for 60–70 years (from 30–40 to 100 years old)
- Production increased during Civil War
- Leading producer is Canada (Quebec)
- Analogous birch syrup from *Betula* is more poor, only 1–2% of sugars

### Sugar collection





Sugar evaporation





## 26.4 Sugar palms

### Arenga sugar palm, *Arenga pinnata*

- Belongs to palm family, Palmae
- The source of “gur” sugar and also wine
- Inflorescences are used for taking sap (17–20% of sucrose)

### Arenga sugar palm



### Arenga sugar palm features and history

- Syrup are very easily inverted (hydrolyzed into glucose and fructose) and should be evaporated as soon as possible



- Every day, palm tree gives 5–7 liters of sap; the season is up to 8 weeks
- Old Indian culture spread into south-east Asia

### Collection of palm sap



### Toddy, *Caryota urens*

- African sugar palm, one of the largest palms
- Monocarpic tree, dies after flowering
- Since the sap is fermented fast, it mostly used as a source of palm wine ( $\approx 1\%$  of alcohol)
- Starred in groundbreaking novel “The Palm Wine Drinkard” by Nigerian author Amos Tutuola



Toddy palm



Toddy palm on flowering stage





Palm-wine drinkard



## 26.5 Lesser sugar plants

Sweet sorghum, *Sorghum saccharatum*

- Grass, selection started in 1940s
- Similar in agriculture, but much less demanding plant than sugar cane
- 10–20% of sucrose in stems
- Now cultivated mostly in U.S. and Argentine

Sweet sorghum





**Mezcal, tequila agave, *Agave tequilana***

- Monocarpic Mexican plant from asparagus family (Asparagaceae)
- The sap is rich of sugars, mostly fructose
- Used mostly for alcohols like mezcal, pulque and tequila

**Mezcal**





**Japanese raisin tree, *Hovenia dulcis***

- Large East Asian tree from buckthorn family, Rhamnaceae
- Large fruit stalks (“subsidiary fruits”) may be used as replacement for honey
- Has several medicinal properties (e.g., helps recovery from alcoholism)
- Many other fruits were and are used as sugar sources: most notable are Mediterranean **grapes**, **apricots**, **melons** and **figs**.

**Japanese raisin tree**



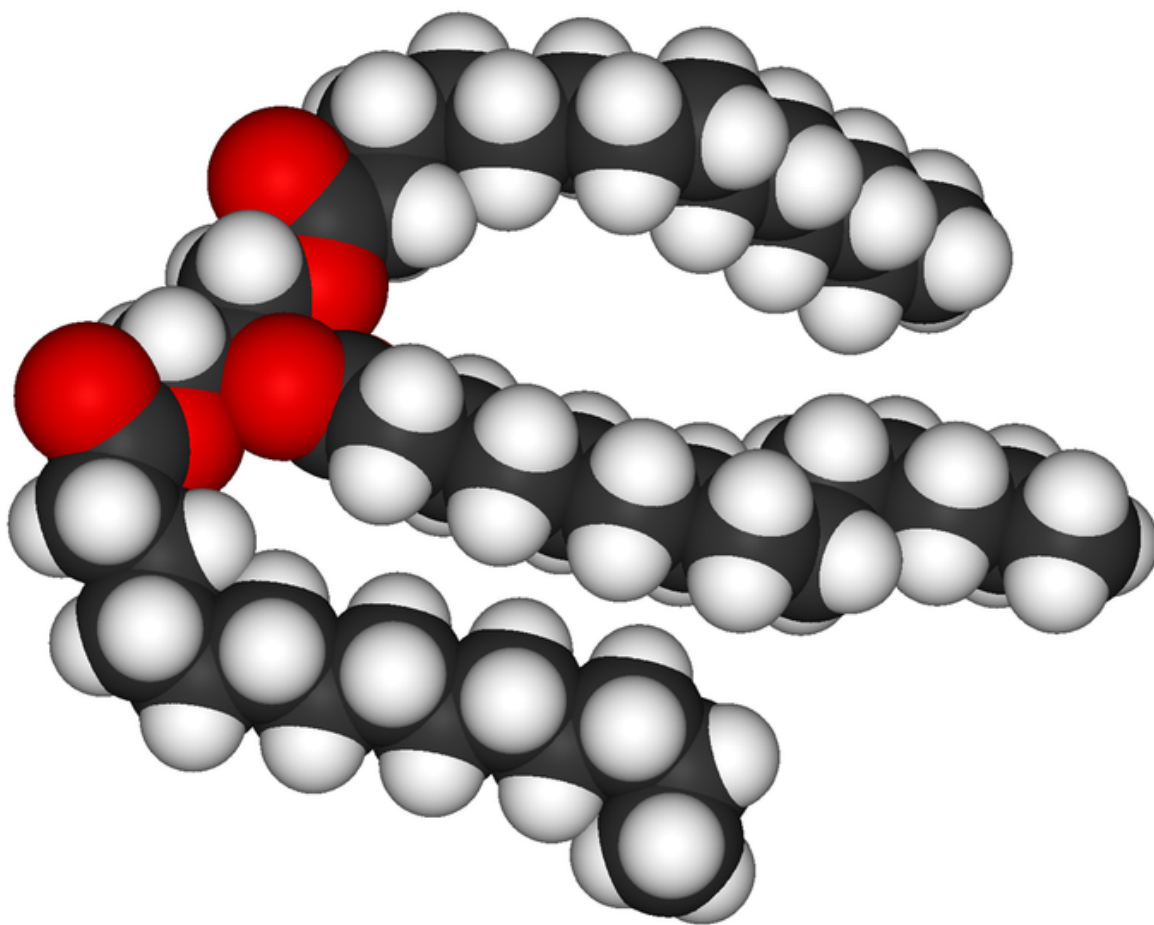
## 27 Oil plants

### 27.1 Introduction to oils

What are oils

- Triglycerides: triesters of glycerol and saturated or non-saturated fatty acids
- Liquid triglycerides are **oils** whereas hard are **fats**
- *Hydrogenated* oils are hard derivatives of liquid plant oils

Triglycerides



## Summary

- Two plants produce more than  $\frac{2}{3}$  of sugars: sugar beet (production is increasing) and sugar cane (decreasing)
- Many tropical sugar plants are used mostly for alcohol production

## For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)
- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

## Outline



## Martenitsa tree (Balkan tradition)



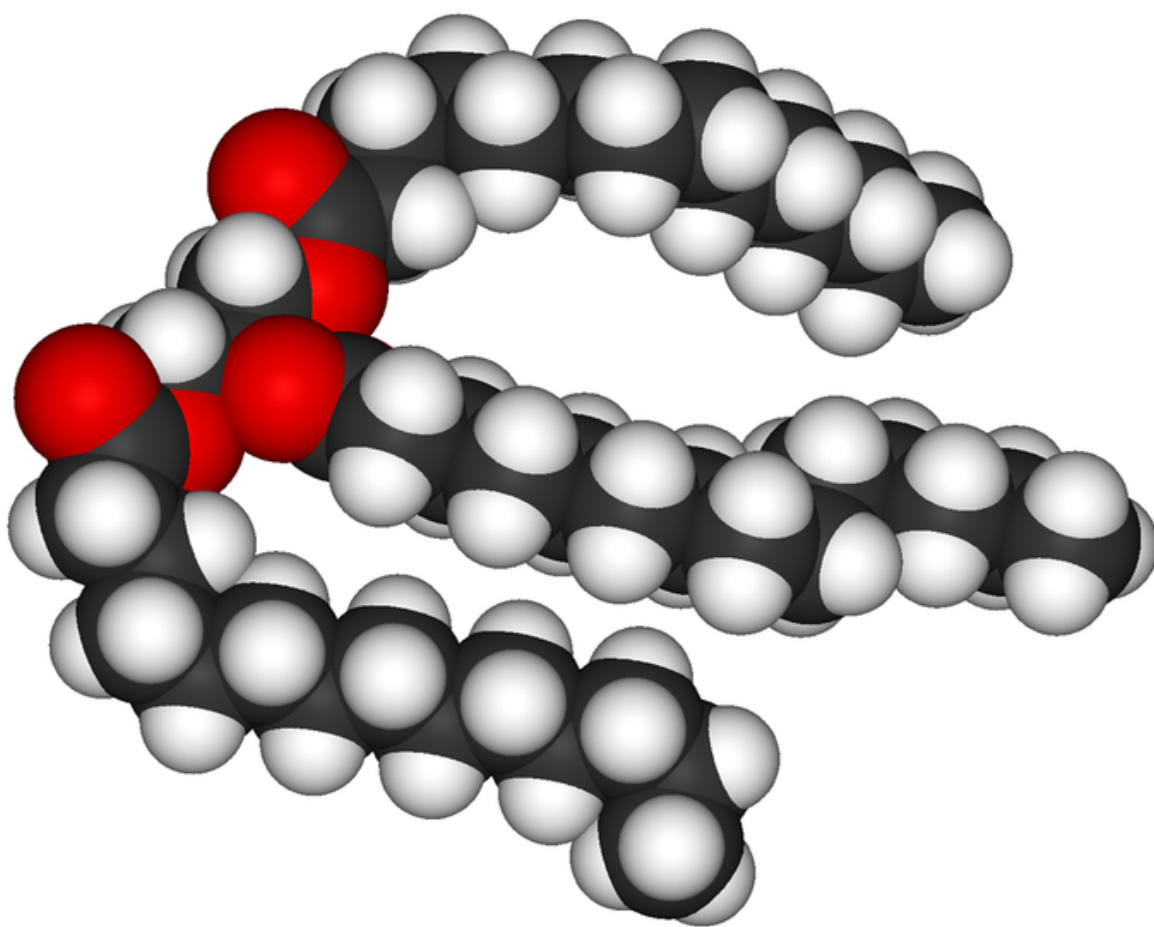
## 28 Oil plants

### 28.1 Introduction to oils

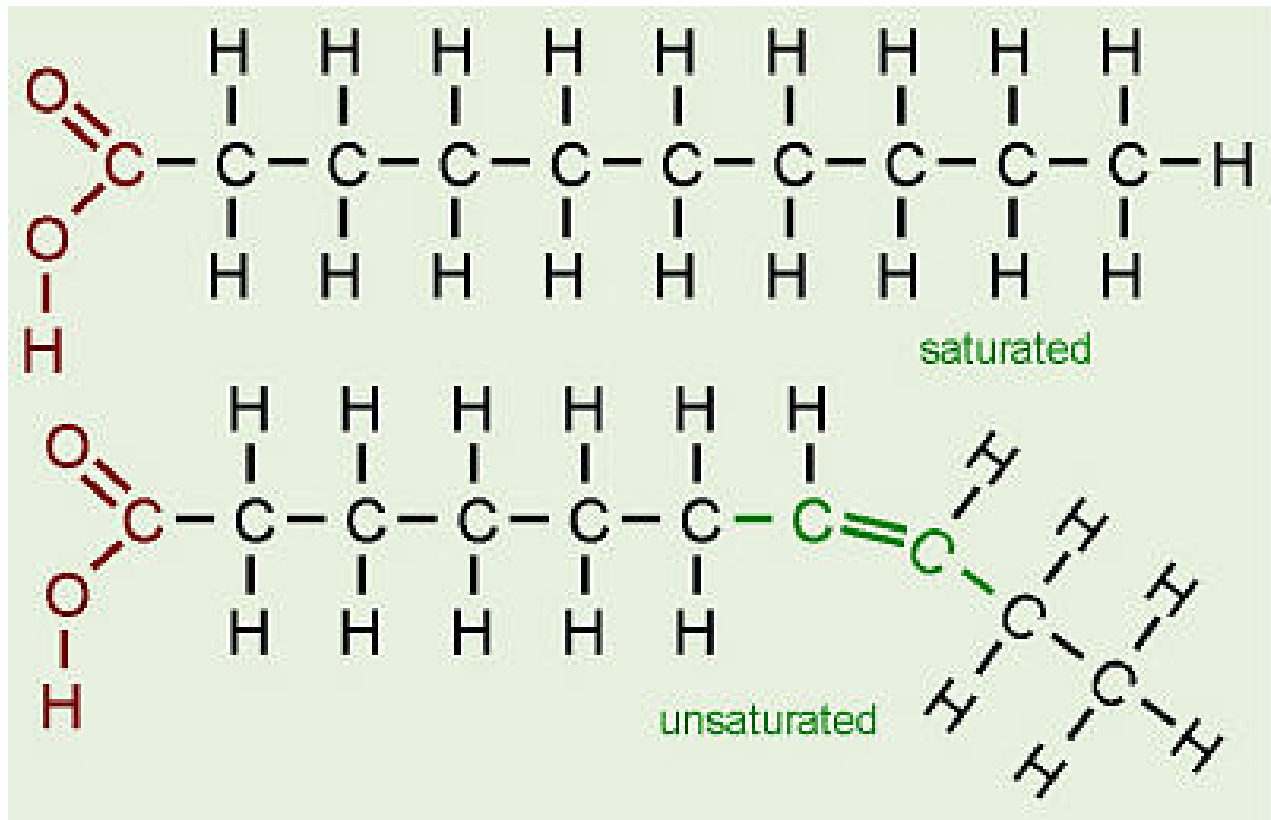
What are oils

- Triglycerides: triesters of glycerol and saturated or non-saturated fatty acids
- Liquid triglycerides are **oils** whereas hard are **fats**
- *Hydrogenated* oils are hard derivatives of liquid plant oils

Triglycerides



Fatty acids



### Oils features

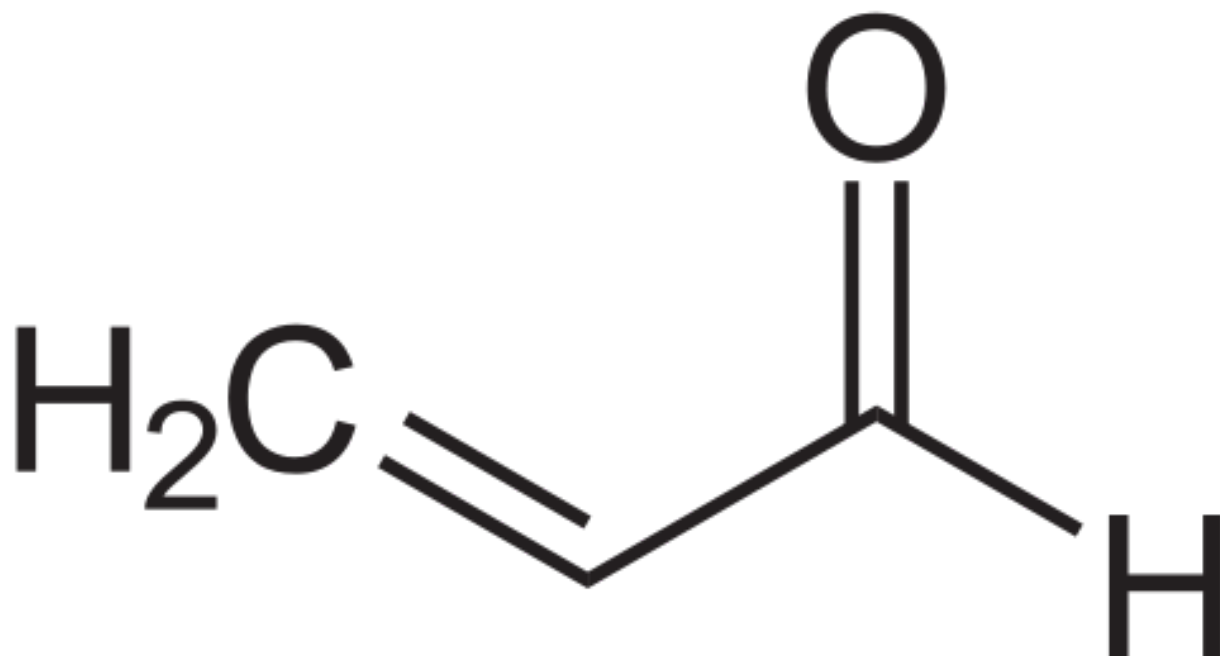
- High energy: 9 calories per gram, two times more than carbohydrates or proteins
- Slow metabolism, several times slower than of carbohydrates

### Smoke temperatures

- Under high temperatures, oils start to smoke: this is due to acrolein
- Acrolein is highly toxic (even used as chemical weapon in World War I)
- Cream butter has  $\approx 175^{\circ}\text{C}$  smoke point whereas many plant oils like peanut have  $\approx 250^{\circ}\text{C}$  smoke point; flax oil is an exception ( $\approx 107^{\circ}\text{C}$ )

### Acrolein

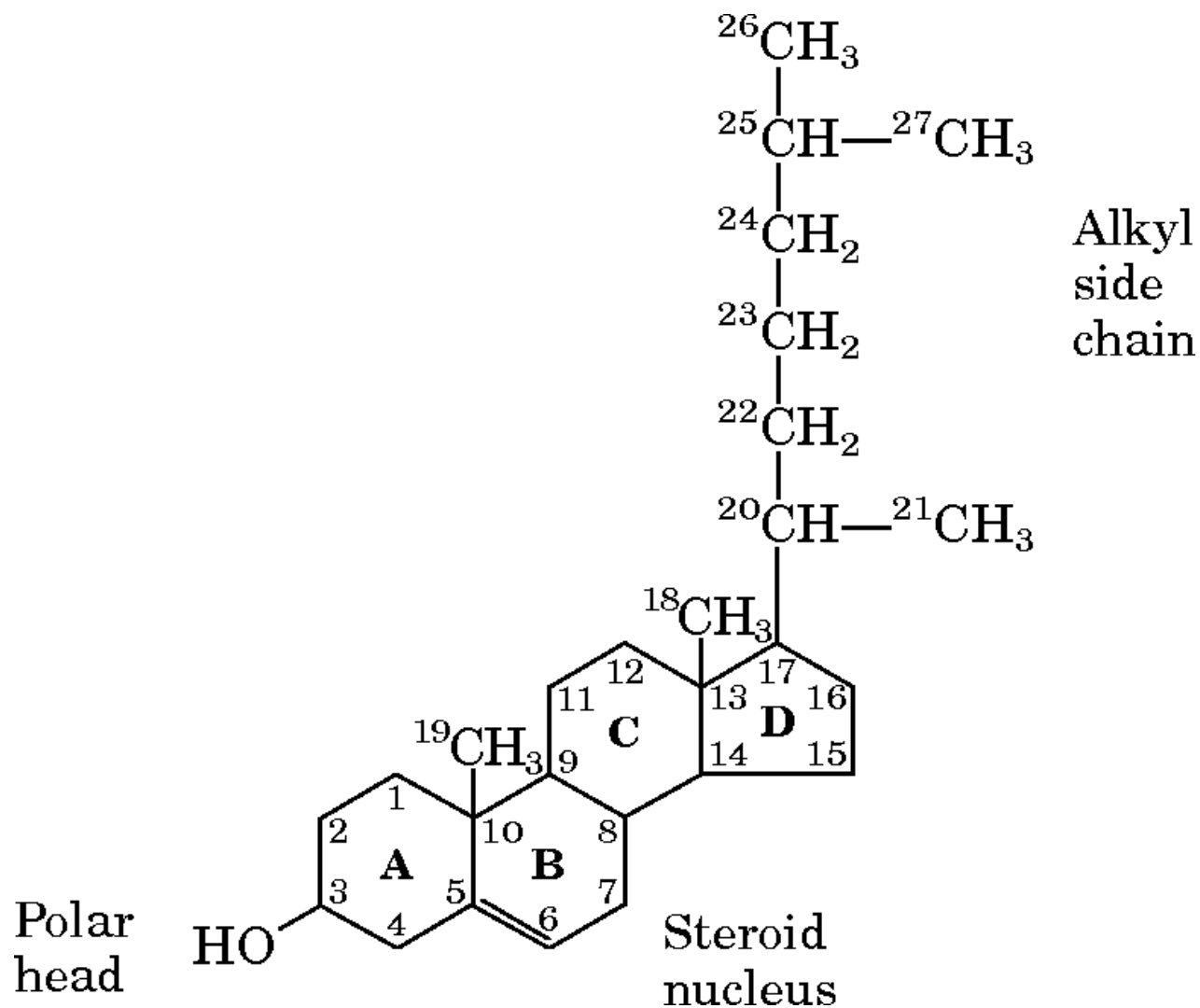




## Cholesterol

- Cholesterol is a main component of membranes and predecessor of steroid hormones
- However, suspicions raised that high level of cholesterol corresponds with atherosclerosis (Ancel Keys' conception of "Mediterranean diet")
- The most risky group are men of age 35–55
- Recent experiments suggest that cholesterol level has **only weak or no relation** with vessel diseases:
  - <http://www.ncbi.nlm.nih.gov/pubmed/16340654>: 70% of human population are hyporesponders to dietary cholesterol
  - <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3900007>: population and individual differences are more important than diet
- Plant oils do not contain cholesterol

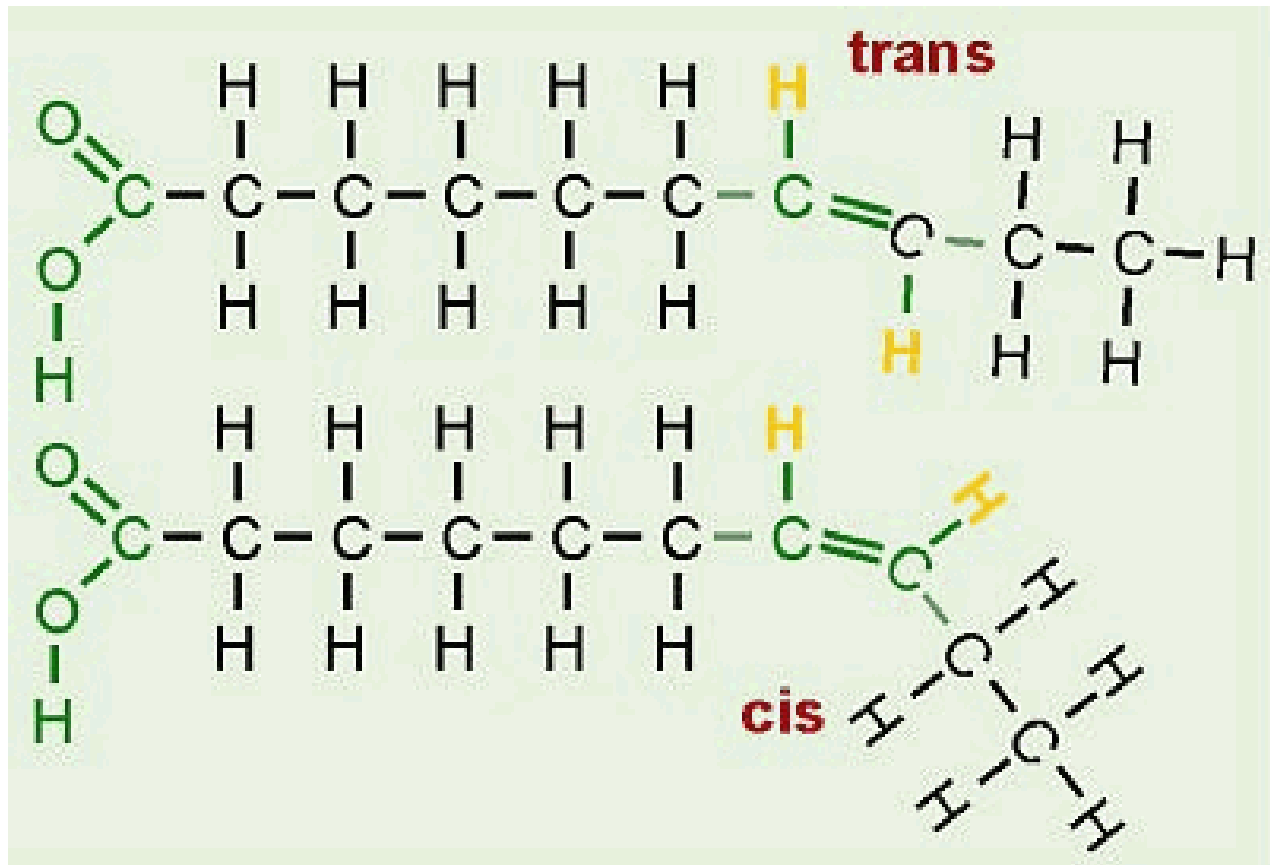
## Cholesterol



### Trans fats

- Trans fats are byproducts of hydrogenation of plant oils, they also may appear in deep fat frying
- Again, *suspicion* is that trans fats are related with heart diseases
- Now most of hydrogenated oils (margarines) are almost free of trans fats

### Trans fatty acids

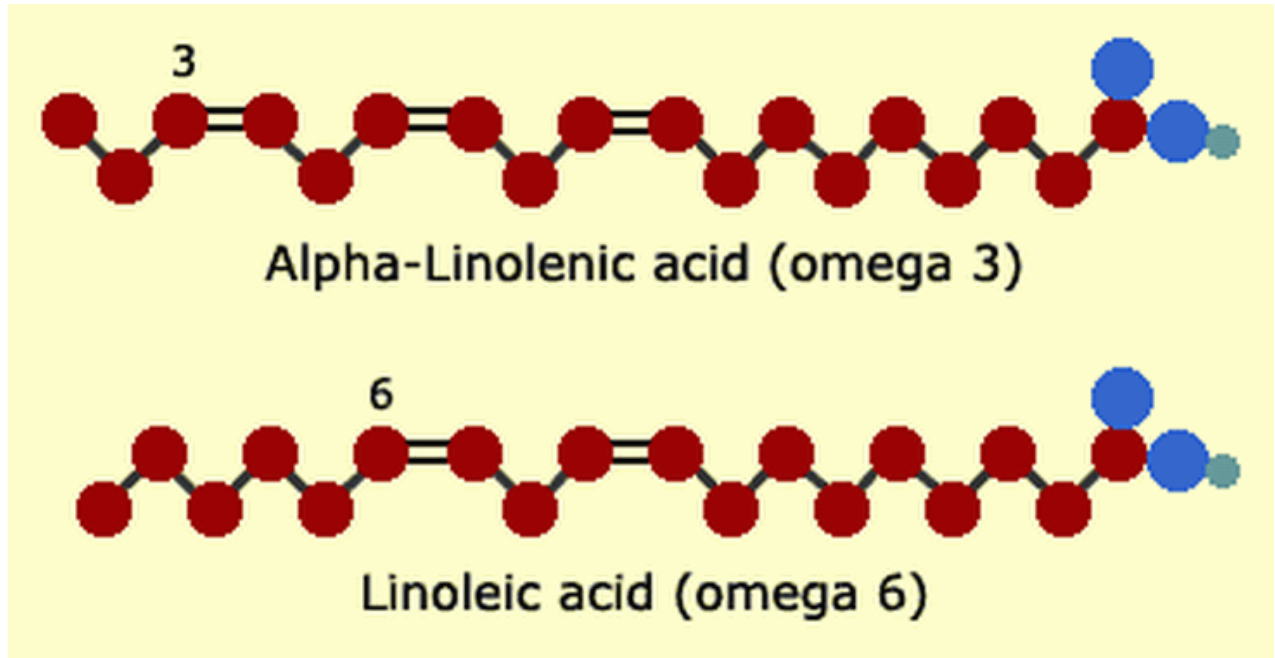


### Omega-n-unsaturated fatty acids

- Essential fatty acids that may only be synthesized in plants
- They *probably* related with lowering of cholesterol level, with curing Type 2 diabetes, and with general lowering of cardiovascular mortality
- Canola, flax and soybean oils contain significant amounts of omega-3-unsaturated fatty acids (and also sea fishes)

### Omega-n-unsaturated fatty acids





## 28.2 Sunflower, *Helianthus annuus*

### Sunflower, *Helianthus annuus*

- Belongs to aster family, Compositae
- Big genus distributed in North and South (but not Central) Americas
- Only one species, *Helianthus annuus* is cultivated as an oil plant

### Sunflower biology

- Annual plant (exception among sunflowers!)
- Young plants are highly heliotropic
- Up to 65% of oils in seeds
- Used also as forage plant, especially in northern regions
- Coordinates of flowers in the head are explained with Vogel's model:

$$r = \sqrt{n}; \quad \theta = n \times 137.5^\circ,$$

where where  $\theta$  is angle,  $r$  is the distance from the center,  $n$  is the index number of the floret, and  $c$  is a constant.

## Sunflower head



## Sunflower agriculture

- Requires light and aerated, rich soils; root system allows to use water from deep layers of soil; requires phosphorus
- Vegetation period 70–140 days
- Wind- and insect-pollinated plant
- Oil is pressed similarly to most oil plants
- There are also nut cultivars

## Sunflower history

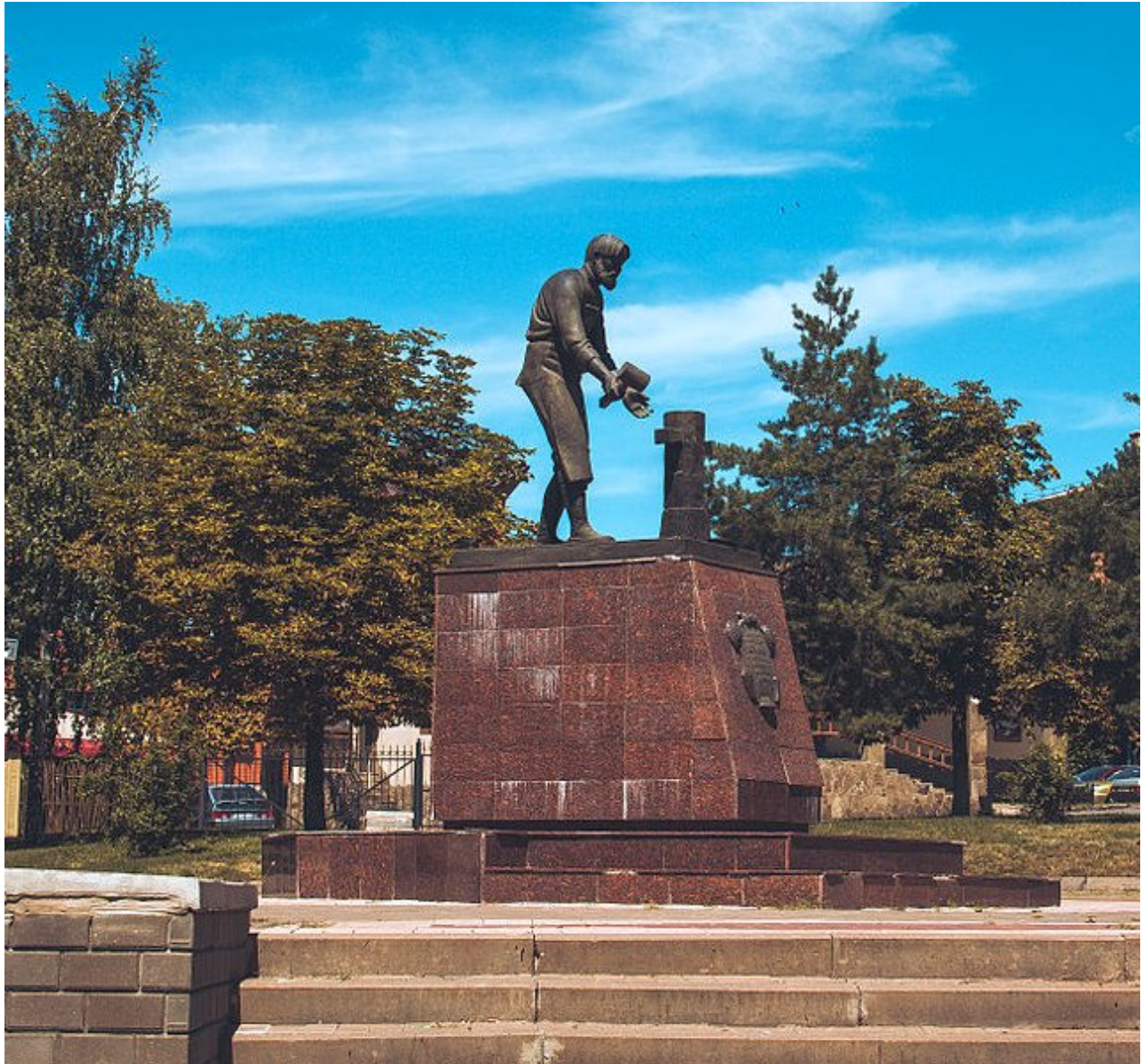
- Domesticated most probably in North America, widely used by native tribes in New Mexico and other southern states
- Went to Europe in 1510, cultivated as ornamental and forage plant and then abandoned
- In Russia, folk selection resulted in fasciated cultivars which have several times more seeds per head
- In 1829, Russian peasant Daniil Bokarjov discovered the high oil content and made first sunflower oil
- Ukraine, Germany and United States are now main producers
- Symbol of Ukraine, state flower of Kansas

Fasciation: elongation of apical meristem



Bokarjov memorial in Alekseevka, Belgorod region





### 28.3 Peanut, *Arachis hypogaea*

#### Peanut, *Arachis hypogaea*

- Belongs to legume family, Leguminosae
- Geocarpic plants: fruits are burying into the ground
- One of the most protein-rich oil plants (53% oils, 25% proteins)

[We skip here soybeans which were described on previous lectures]

#### Peanut biology

- Small, self-pollinated plant with flowers positioned nearby soil surface
- Burying structure is a gynophore, part of flower receptacle



- Legumes are indehiscent, contain 2–3 seeds
- 1–2% of human population have peanut allergy to peanuts (consequence of high protein content)

## Peanut



## Peanut agriculture

- Vegetation is 3–5 months
- Requires warm temperatures, average humidity (500–1,000 mm) and light, sandy soils
- As a legume, does not need many fertilizers
- Susceptible to fungus contamination in storage: some fungi produce toxic *aflatoxin*

## Peanut history

- Cultivated species is a tetraploid originated from hybridization of two South American wild species
- In valleys of Peru, cultivated from 5,600 BC
- In XVII century, went independently to Africa and Asia
- Biggest producers now are China, India and U.S. Main crop in several West African countries, e.g., Ghana.
- Hundreds of cultivars, in U.S. there are mostly “Runner” and “Virginia” groups

## 28.4 “Canola”, rapeseed, *Brassica napus*

### “Canola”, rapeseed, *Brassica napus*

- “Canola” stands for “**can**adian oil”, name of the group of cultivars of rapeseed, *Brassica napus* from cabbage family, *Cruiferae*
- One of the most hardy oil plants
- New culture, only in 1970s started to be used widely

### Canola

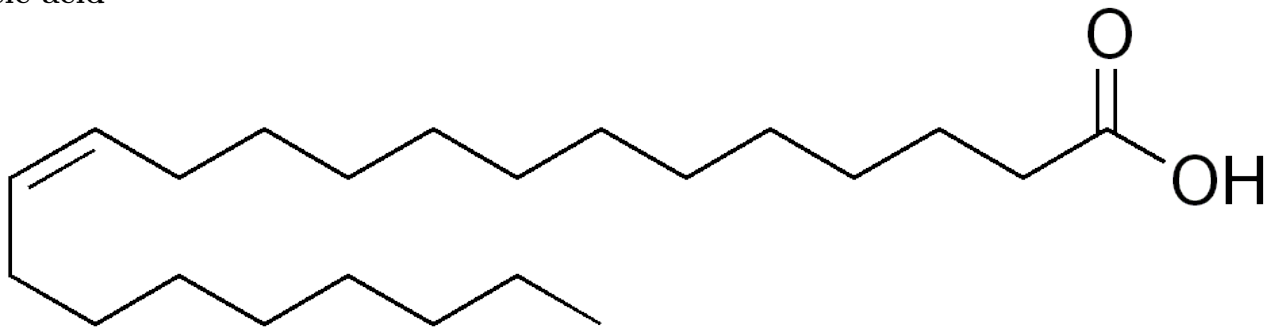


### Canola biology

- Medium-sized (up to 1.5 m tall) herbaceous annual, cultivated as winter or as spring crop
- Seeds contain high amounts of unsaturated oils including omega-3 oils
- Cross-pollinated, produces significant amounts of nectar
- Non-canola cultivars contain potentially toxic erucic acid and glucosinolates
- Erucic acid, however, is used as four-to-one mixture with oleic acid and constitutes “Lorenzo’s oil” (there is a movie with same name); an experimental treatment for the rare neurobiology disorder adrenoleukodystrophy



### Erucic acid



### Canola agriculture

- Relatively easy culture, requires water and cool temperatures, long-day plant
- Needs high amounts of fertilizers
- Harvesting should be fast because siliques are dehiscing fast

### Canola siliques



### Canola history

- Domesticated in Europe
- Cultivated for a long time but mostly as technical oil plant
- In 1974, zero-rapeseed was selected which contained less than 2% of erucic acid; in 1982, 00-rapeseed which contains almost 0% of erucic acid: canola
- Canola cultivars are susceptible for fungal diseases (erucic acid was a defense agent)
- Canola also susceptible to cross-pollination with technical rapeseed
- Biggest producers now are China, Canada and India

## 28.5 Olive, *Olea europaea*

### Olive, *Olea europaea*

- One of the oldest oil plants, also used as vegetable
- Belongs to olive family, Oleaceae
- Relatively hardy plant despite of evergreen life form

### Olive biology

- Evergreen, long-lived (up to 2,000 years), small tree
- Starts to produce fruits from 3–4 year (when grafted)
- Cross-pollinated with wind
- Oil does not contain omega-n-unsaturated fatty acids

### Olives in Greece



### Olive agriculture

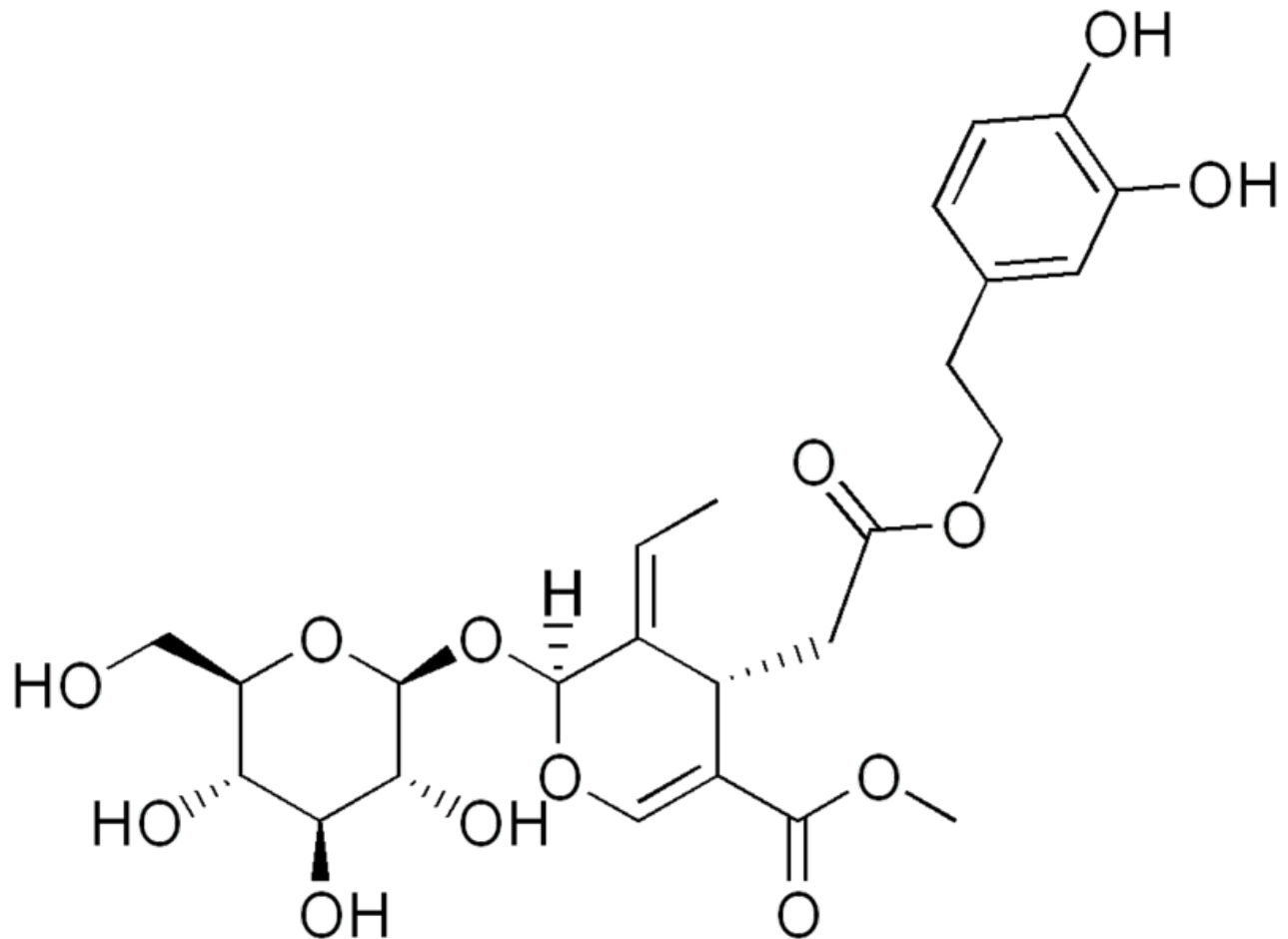
- Requires dry air and lots of sun, does not particular to soils (but grows better on limestone soils)
- One tree may produce  $\approx 20$  kg of fruits per year for 200 years
- Harvested in winter, half-manually, by shaking trees
- Oil is pressed, outer parts are fermented to remove bitter *oleuropein*



## Olive harvesting



## Oleuropein



### Olive history

- Large historical and mythological background: from Old Testament and Greek mythology to Quran
- Cultivation started  $\approx$  6,000 BC in Mediterranean
- More than 500 cultivars; top producers are Spain, Italy and Greece
- Olive became invasive in Australia

## 28.6 Sesame, *Sesamum indicum*

### Sesame, *Sesamum indicum*

- Belongs to the tropical genus *Sesamum* ( $\approx$ 20 species) from sesame family, Pedaliaceae
- The oldest cultivated oil plant

### Sesame



### **Sesame features**

- Tropical herbaceous annual plant, vegetation 3–4 month, yield is 1–2 tons/hectare
- Seeds contain 50-65% of oil; oil contains phytosterols, vitamin E and significant amounts of microelements, especially iron and magnesium
- Can grow in dry climatic zones
- Used entirely (green mass as a forage, pressed cakes in bakery etc.)

### **Fruits and seeds of sesame**





### **Sesame history**

- Cultivation started in India prehistorically, went to ancient Egypt and then to Europe
- Now cultivated mostly in tropics around the world
- Biggest producers are still India and China
- Famous also after Ali-Baba story from “One thousand and one nights”

**Ali-Baba (40 thieves are not at home yet)**



## 28.7 Safflower, *Carthamnus tinctorius*

Safflower, *Carthamnus tinctorius*

- Belongs to Mediterranean *Carthamnus* (distaff thistles) genus and aster family, Compositae
- Highly ornamental cultivated plant
- Multiple uses: as oil plant, as medicinal plant and as saffron substitute (red dye)

Safflower field

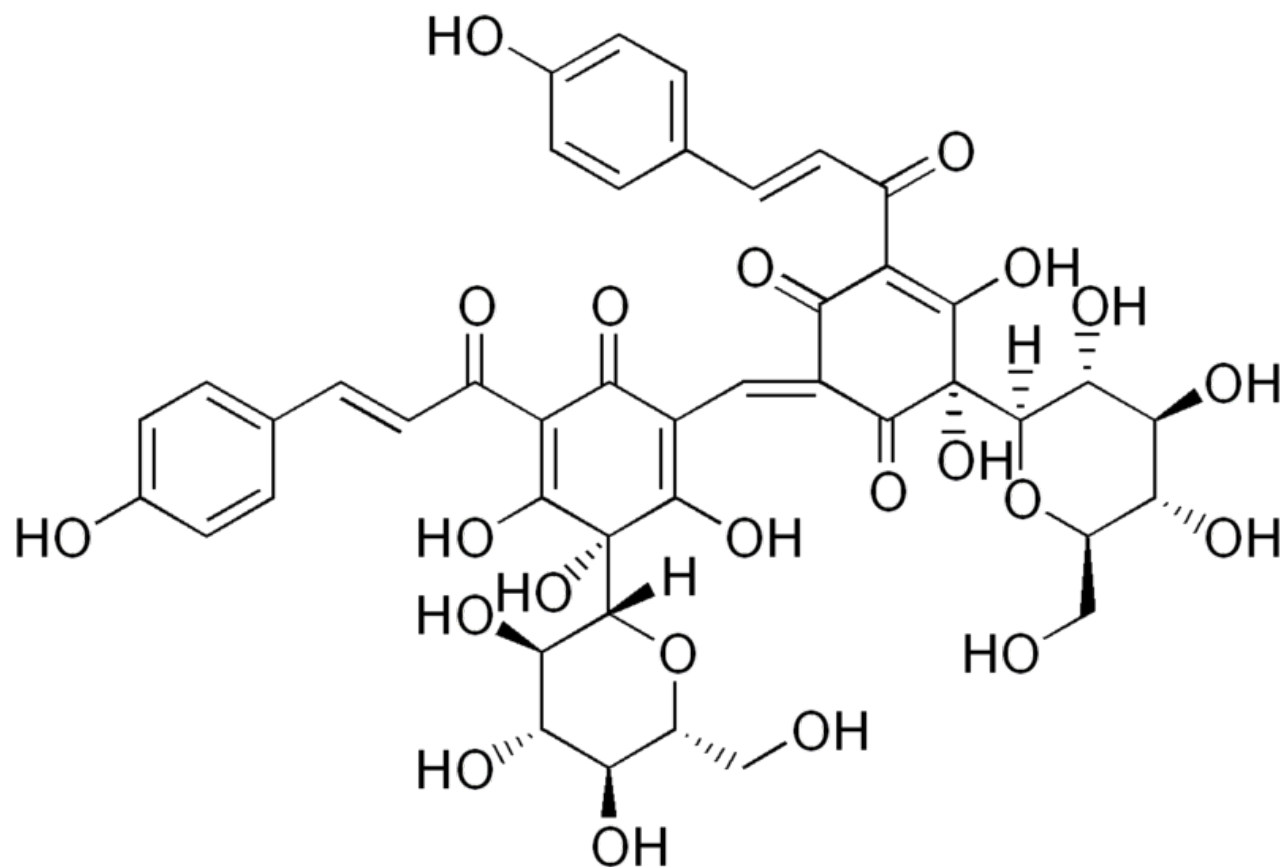


### Safflower features

- Achenes contain 15–35% of oil
- Oil contains mono- and polyunsaturated fatty acids, and therefore may be used for painting (fast-dried oil)
- Flowers contain carthamin which produces a red-brown color, often used in food production
- Rich of tokoferols (vitamin E)

### Carthamin





## Safflower history

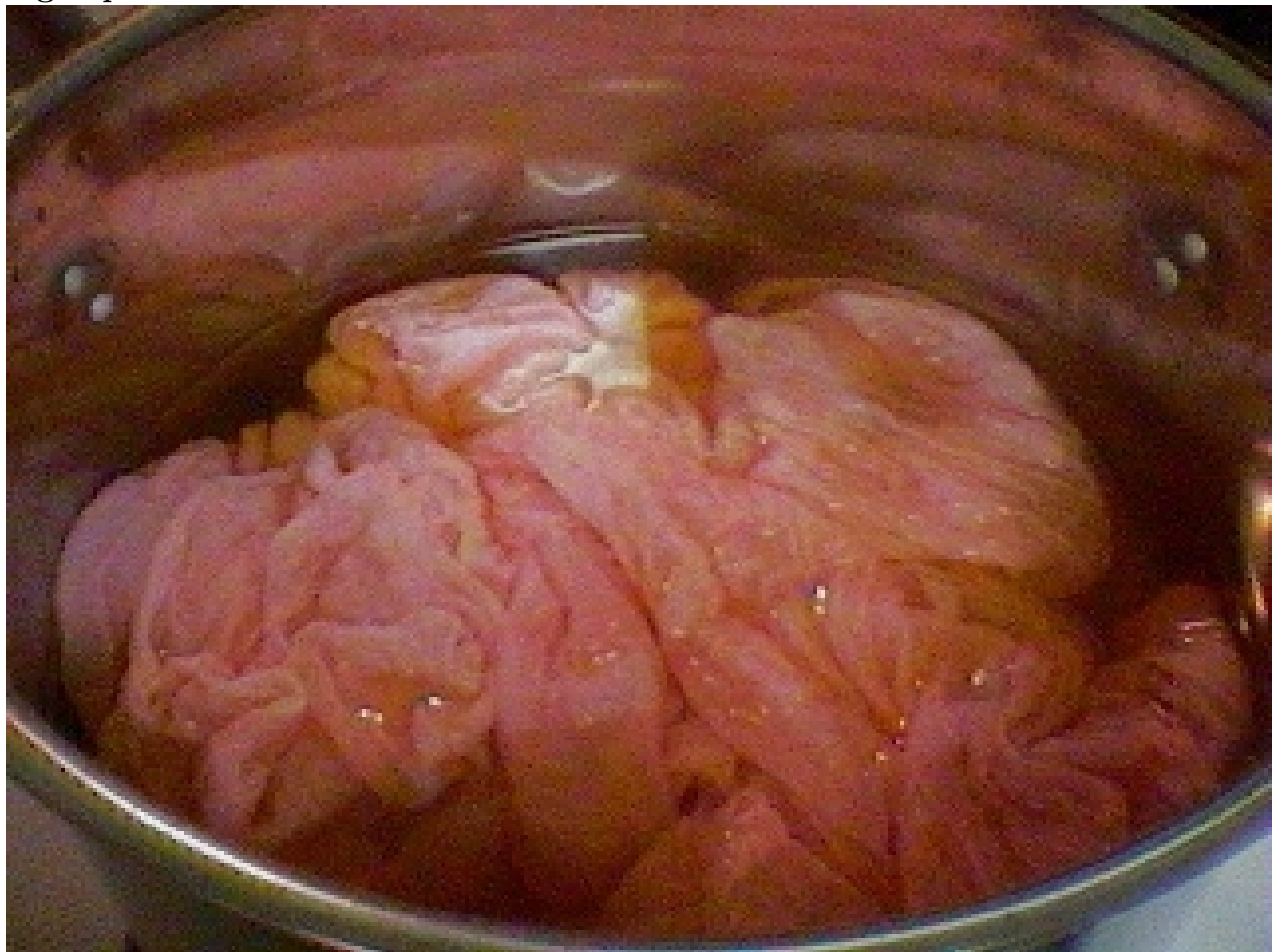
- One of the most ancient cultivated plants, used in Old Egypt
- Went to Japan and used there as a plant which dye had ceremonial meanings

## Harvesting safflower



[From Takahata's "Only yesterday" movie]

Making Japanese clothes



Painted with safflower



Shuntei (1898): *Shadow of the Castle*

## Summary

- All oil plants contain oil (non-saturated triglycerides) in seeds
- The most important oil characteristics are smoke temperature, amount of cholesterol, amount of trans fats and amount of omega-n-unsaturated fatty acids

## For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)



- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

## Outline

# 29 Oil plants

## 29.1 Oil palm, *Elaeis guineensis*

### Oil palm, *Elaeis guineensis*

- Used in Africa from prehistorical times, but the mass cultivation started only in the beginning of XX century
- Belongs to palm family, Palmae
- Palm oils are semi-solid at the room temperature: plant fats

### Fruits of oil palm



## Blocks of palm oil



## Oil palm features and history

- Oil is rich of saturated fatty acids, especially palmitic ( $C_{16}$ ) acid, also rich of carotenes and often has a reddish color
- Yield is high (up to 100 kg of oil from one tree per year), and therefore palm oil is very common in tropics
- Biggest producers are Malaysia and Indonesia
- Also famous as the source of Greek fire and **napalm** (mixture of palmitic acids, several other organic compounds and aluminum)

## Making of palm oil (Kongo)





Napalm





## 29.2 New oil cultures

### Sacha inchi, *Plunkettia volubilis*—perspective oil plant

- South American, Amazonian tree from spurge family, Euphorbiaceae
- Capsules contain several large seeds, rich of oil ( $\approx 60\%$ )
- Sacha inchi oil contains highest amounts of omega-n-unsaturated fatty acids (93%!) and vitamin E
- Cultivation started in 2000s, mostly in Peru

#### Sacha inchi



## 29.3 Lesser oil plants

### Coconut, *Cocos nucifera*

- Belong to Palmae, cultivated around the world as technical and nut plant
- Oil is similar to Africal oil palm: rich of saturated fatty acids, especially lauric acid (48%)
- Oil extracted from either coconut milk (wet process), or copra (dry process)
- Apart from food, has a wide technical use (lubricant, fuel, cosmetics)

[Coconut palm will be covered in more detail later]

## Drying coconut copra for oil making



## Soybeans, *Glycine max*

[The plant was covered earlier]

- Apart from protein food, soybeans produce one of most widely used cooking oil (“vegetable oil”), with high smoke point (232°C)
- Soybean oil is rich of poly-unsaturated fatty acids (especially 2-unsaturated linoleic, 51%)
- Soybean oil may also be used for painting (because it is drying slowly), as insect repellent, as fuel, and as fixative to essential oils

## Soybean oil



Soybean oil as biofuel





### Flax, *Linum usitatissimum*

- Obtained from flax (*Linum usitatissimum* from Linaceae family) which is also used as technical plant
- Bright yellow, very fast drying oil because it is rich of triply unsaturated fatty acid,  $\alpha$ -linolenic acid (up to 55%), smoke point is low (107°C)
- Normally, used as a technical substance for painting, for finishing wood, for linoleum (one of the first half-synthetic floor covering) and also as rich and useful food supplement ( $\alpha$ -linolenic acid =  $\omega$ -unsaturated acid, EFA)

[The plant will be covered in more details later]

### Wood finishing with flaxseed oil



### Cottonseed, *Gossypium* spp.

- Extracted from seeds of cotton (several species of *Gossypium* from Malvaceae family)
- Oil contains up to 52% stearic (monounsaturated) fatty acid, very stable (does not dry) and with high smoke point (232°C)  
(Rice oil has the highest smoke point, 254°C)
- Used in many foods, especially for salad dressings and chips, for deep frying
- High of tokoferols (vitamin E)
- Contain amounts of *gossypol*—biologically active phenolic compound which may be used in medicine (e.g., as contraceptive, for curing viral infections etc.) but should be removed from food oil

[Mostly known as a fiber plant, will be covered later]

### Cottonseed oil



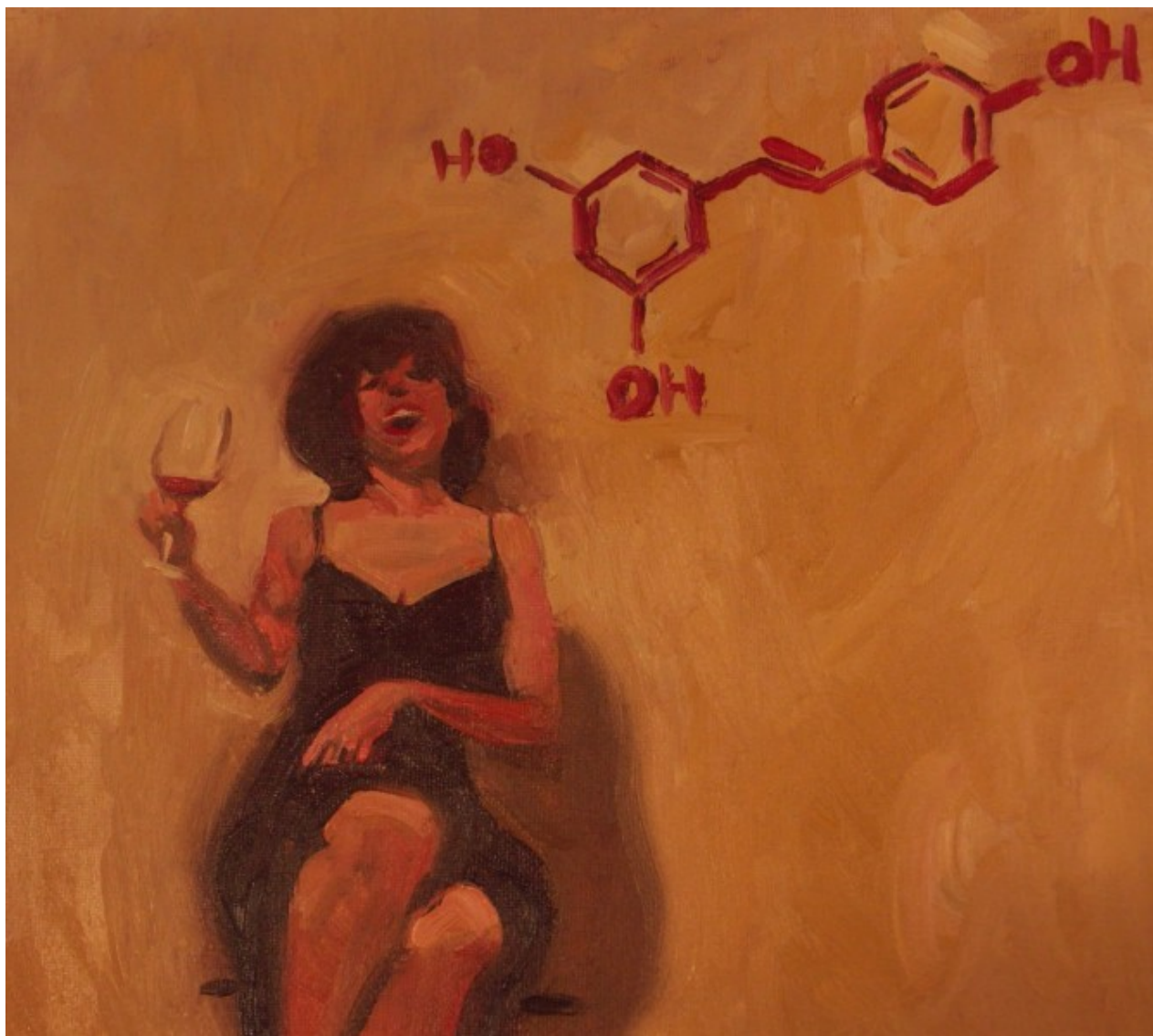
### Grapeseed, *Vitis vinifera*

- By-product of winemaking, extracted from grape (*Vitis vinifera* from Vitaceae family)
- Similarly to soybean oil, rich of 2-unsaturated linoleic acid (72%)
- Used similarly to cottonseed oil: salad dressings and deep frying
- Has high medicinal value: contains *phytoalexin* (plant non-specific immune chemical) **resveratrol** (also component of red wine) which is anti-cancer and anti-hypertensive drug

[Mostly known as fruit, will be covered later]

### Resveratrol





### Cocoa butter, from *Theobroma cacao*

- Cocoa butter from *Theobroma cacao* (Malvaceae family) is plant fat, rich on non-saturated fatty acids (stearic and palmitic together  $\approx 60\%$ )
- Has  $37^{\circ}\text{C}$  melting temperature and therefore used a lot as a subsidiary oil in medicine (e.g., in suppositories) and in cosmetics; also used for making white chocolate
- Normally, does not contain theobromine and caffeine (components of dark chocolate)

[The plant will be covered in more details later]

### Cocoa flower



**Shea butter, from *Vitellaria paradoxa***

- Shea butter from *Vitellaria paradoxa* (Sapotaceae, you already know miracle fruit from this family) is similar to cocoa butter (with similar melting temperature)
- African tree
- It has a double use as edible and as technical
- Used for cosmetics from Ancient Egypt times

**Shea tree**



Traditional preparation of the shea butter





## Summary

- Oil palm and cocoa tree produce high amounts of plant “fats”
- The most promising contemporary oil cultures are canola and sachu inchi

## For Further Reading

## References

- [1] A. Shipunov. *Ethnobotany* [Electronic resource]. 2011—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310](http://ashipunov.info/shipunov/school/biol_310)
- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

## Outline

## 30 Oil plants

### 30.1 Technical oil plants

#### Essential oils

- Mixture of hydrophobic components bearing plant odors
- Used for aromatherapy and in cosmetics
- The most famous are probably rose oil and eucalyptus oil

#### Ylang-ylang, *Cananga odorata*

- Tree from custard apple family (Annonaceae) which is cultivated for perfume oil
- Fast-growing tree from Indonesia
- Has diverse medical applications, used for cosmetics (Chanel No. 5) and in aromatherapy
- Comoros is the biggest exporter of ylang-ylang (29% of its annual export)

#### Ylang-ylang





## Camphor tree, *Cinnamomum camphora*

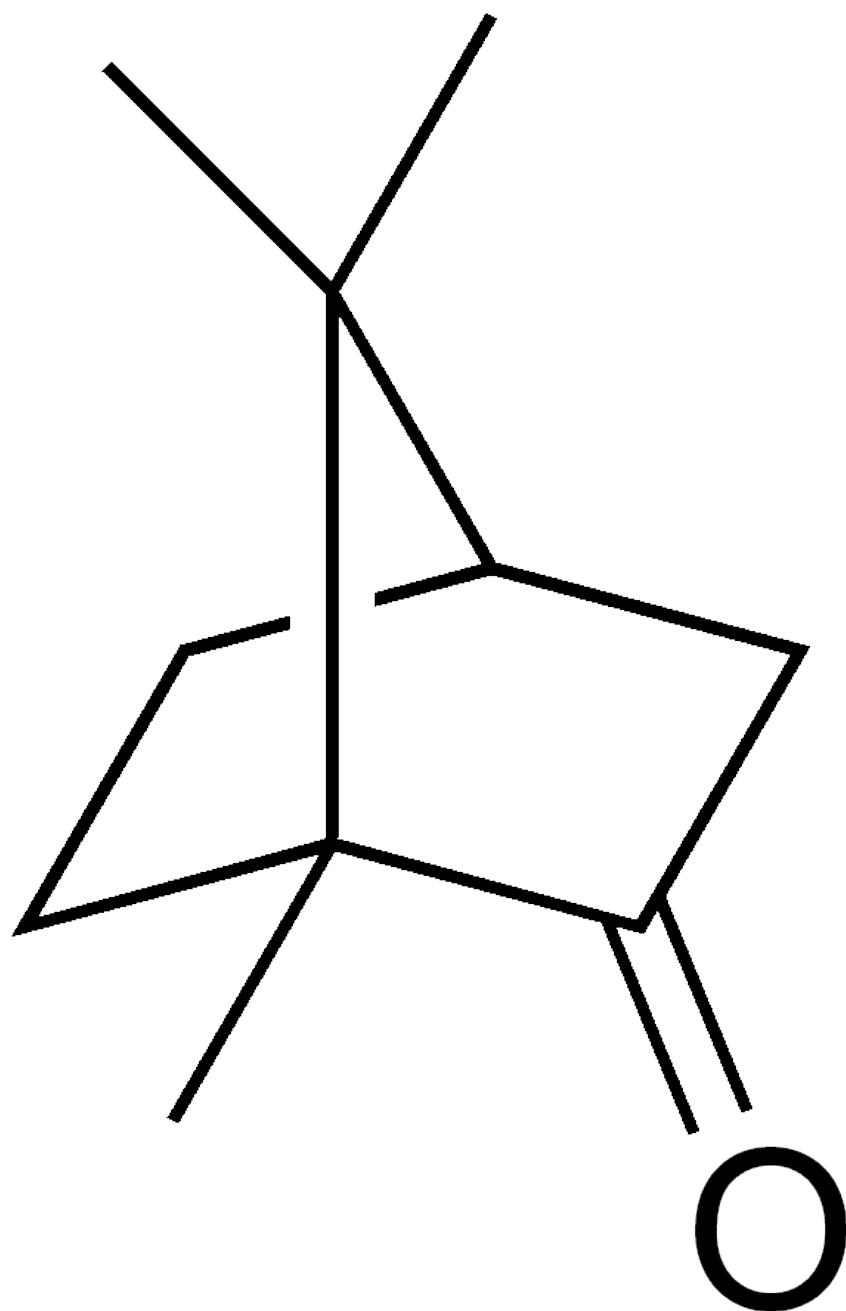
- East Asian tree from laurel family, Lauraceae
- Contain multiple aromatic substances, e.g., camphor—unusual hydrophobic molecule
- Camphor use has the old history, it still has a high ceremonial value in Hinduism, used in sweets, for aromatherapy and in fireworks (highly flammable)
- It is a Totoro tree from H. Miyazaki's "My neighbor Totoro" anime film

## Camphor tree



## Camphor: chair molecule





Totoro on the top of camphor tree



[From Miyazaki's "My Neighbor Totoro"]

**Tung, *Vernicia (Aleurites) fordii***

- Small East Asian deciduous tree from spurge family, Euphorbiaceae
- Highly poisonous seeds contain one of the best drying oils, rich (82%) of 3-unsaturated  $\alpha$ -eleostearic fatty acid
- Used for finishing wood (especially for musical instruments) and other staining processes

**Tung fruits**



**Castor oil plant, *Ricinus communis***

- African and Indian shrub from spurge family, Euphorbiaceae
- Cultivated as annual in temperate regions
- Seeds are poisonous, but contain (95%) unique castor oil containing hydroxylated ricinoleic oil (unsaturated oil with –OH group)
- Widely used in traditional medicine as laxative, now used in many modern drugs as a component, and also as technical oil for lubrication, making plastics etc.
- In fascist Italy, was widely used for intimidation of Mussolini opponents (oil is not poisonous but in large quantity may be harmful)

**Castor plant**





**Jojoba, *Simmondsia sinensis***

- Shrub of its own family (Simmondsiaceae) native to southern North America
- Name is a result of botanical mistake: botanist J. Link misread label “Calif” as “China”
- Seeds contain unique liquid wax (10°C is a melting point): combination of long-chained fatty acids and fatty alcohols
- Jojoba “oil” is odorless, colorless and oxidatively stable, used as a substitute for sperm whale oil: cosmetics, as stable lubricant (it is not digested for most organisms); and now also as biofuel
- Widely cultivated in Arizona, California and Mexico

## Jojoba male flowers



## Summary

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## For Further Reading

## References

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- [2] P. M. Zhukovskij. *Cultivated plants and their wild relatives* [Electronic resource]. Commonwealth Agricultural Bureaux, 1962. Abridged translation from Russian. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_310/zhukovskij1962\\_cultivated\\_plants.djvu](http://ashipunov.info/shipunov/school/biol_310/zhukovskij1962_cultivated_plants.djvu).

Also, check out all presentation slides.