For the Oregon Brew Crew
March 2013

Temperature and Brewing

Malting Overview

- Raw barley kernels are soaked in water, then allowed to germinate
- Partial germination breaks down walls inside the kernel. Enzymes that degrade starch are released, and 30-40% of the protein is degraded to soluble compounds (important for FAN)
- The kernels are dried and heat cured
- Optional kilning for color and flavor

Temperature and Malting

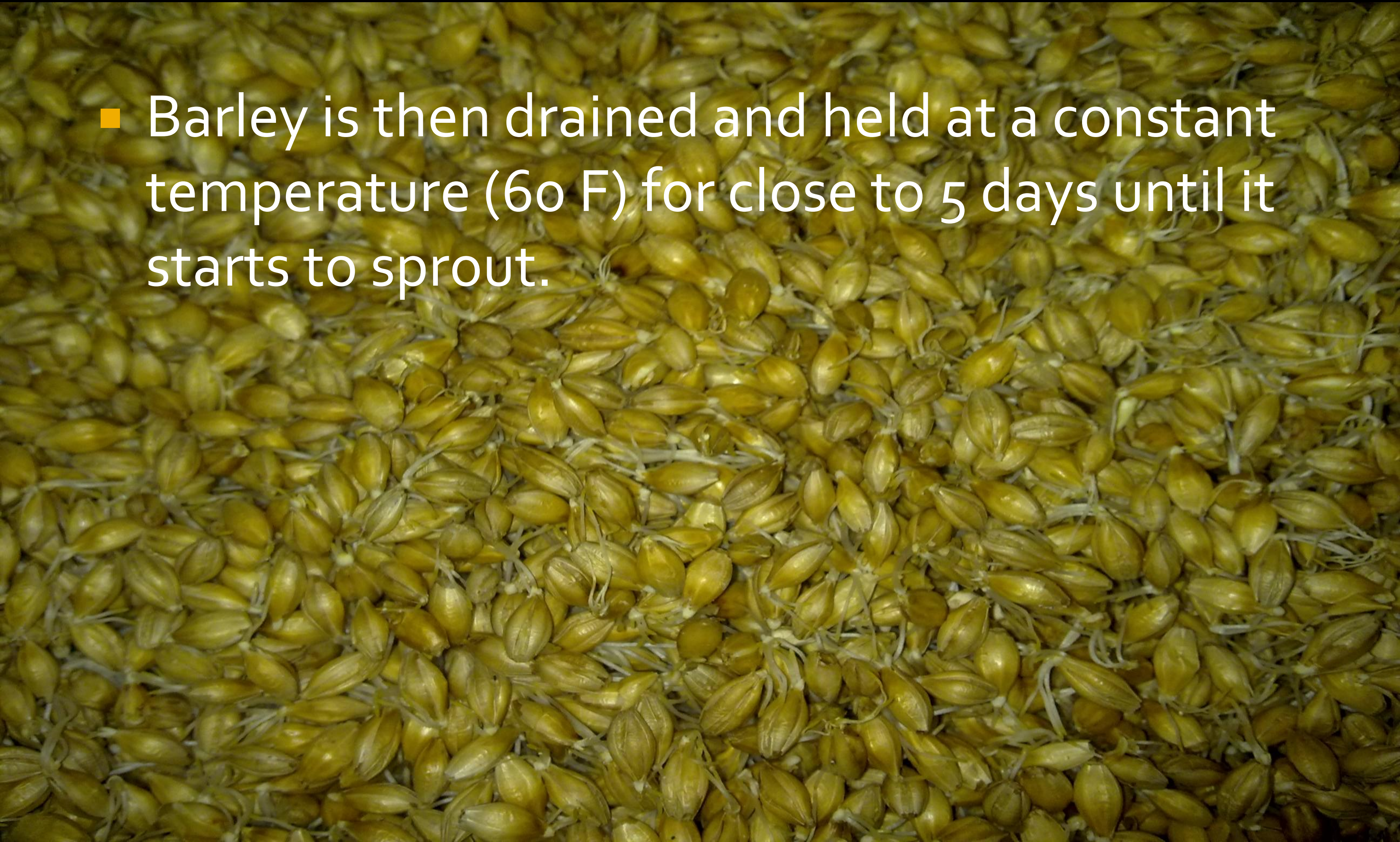
- Where is temperature important and why?

- Soaking
- Germination
- Production of Crystal Malt
- Kilning
- Roasting

Soaking

- When barley arrives it is dry
- Grain is soaked to hydrate the kernels and give them the signal to sprout and grow
- Too cold or too hot and the barley doesn't germinate
- Optimum temperature: 60.8-64.4° F
- Grows 25% during this process

Germination



- Barley is then drained and held at a constant temperature (60 F) for close to 5 days until it starts to sprout.

Drying and Curing

- The barley is slowly dried in a kiln at temperatures gradually rising to 185 F for lager malts and 221 F for pale ale malts. This kiln drying takes about 30 hours.
- The moisture content lowers from 40-45% to 2-4%

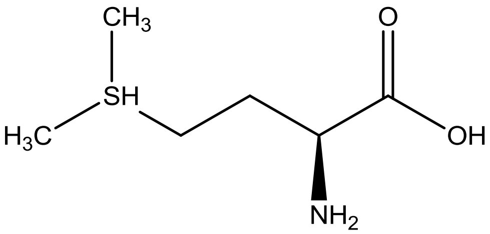
Czech Pilnener	**185°**
Domestic 2 row	189.5°
Pale-ale/Vienna	194°
Munich	221°

Kilning

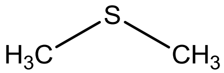
- The kilning temperature affects how dark the malt will be, what flavors it will impart, and its active enzyme levels
- S-Methyl-Methionine (SMM)
- Maillard Reaction

S-methyl-methionine

- Precursor to dimethyl sulfide (DMS)
- Desired in some beers
- Converted to DMS either during kilning or during the boil
- DMS produced during kilning is quickly degraded and is not present in finished malt
- For SMM in malt, temperature does not exceed 149°



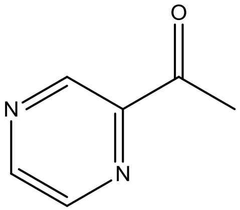
S-methyl methionine (SMM)



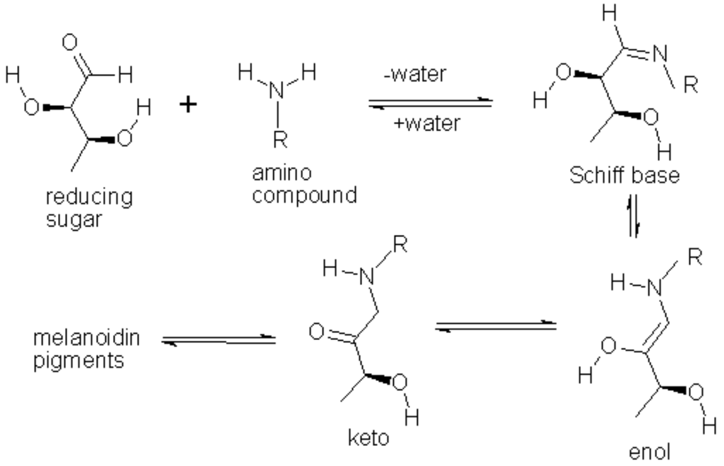
Dimethyl sulfide (DMS)

Maillard Reaction

- Browning reaction involving an amino acid and a sugar + heat
- Produces flavor compounds (melanoidins and heterocyclic compounds) that add “toasty”, “burnt”, “caramel”, “smoky” malty flavors and aromas
- Occurs at ~212° F



2-acetyl pyrazine



Crystal Malt

- Produced by holding the wet warm barley post-germination at a set temperature
- Partially mashes and liquefies the starch
- Accomplished by holding the grain at 149-158° for 30 mins-2 hours and then continuing to dry/cure
- Dark crystal is obtained by elevating the temperature to 248-302° for 1-2 hours
- Carapils is dried at a lower temperature

Roasted Barley

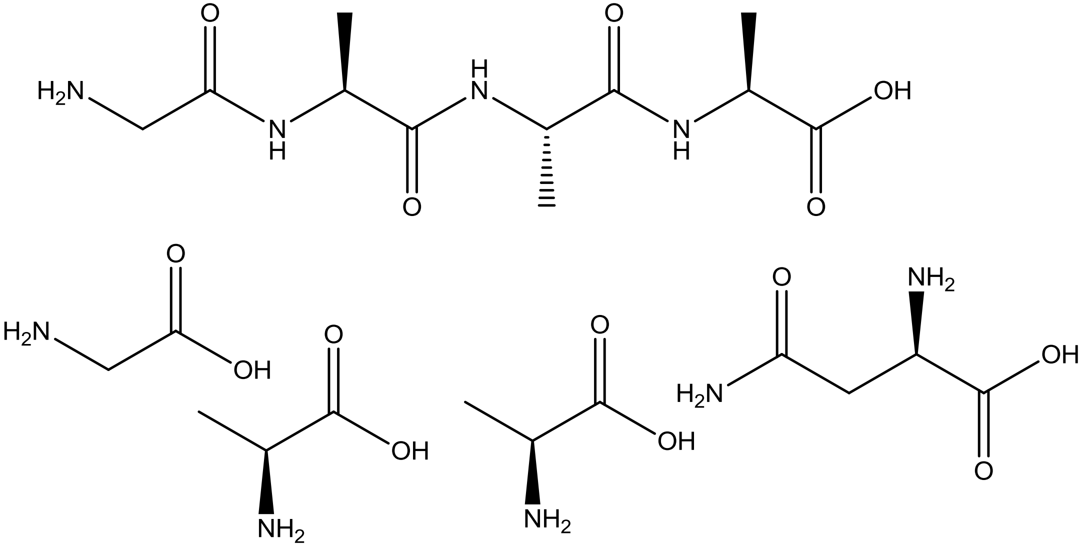
- The very rapid color development that occurs is monitored by inspecting grain samples, which are taken every 2-3 min. The amount of heat applied in the final stages is continually reduced until, when the temperature reaches about 419°F, the burners are turned off. However, the grain is near combustion and the temperature continues to rise spontaneously for the last 5 min or so to about 425°
- When the operator judges the color is correct (just before the grain catches fire) the barley is cooled with sprays of water. The risk of fire is great and roasthouses are generally isolated and constructed with this risk in mind.
- All enzymes and sugars are consumed

Mashing

- Starch is converted to sugars by enzymes
- Proteins are broken into peptides
- Glycoproteins are formed
- Percent fermentability is determined

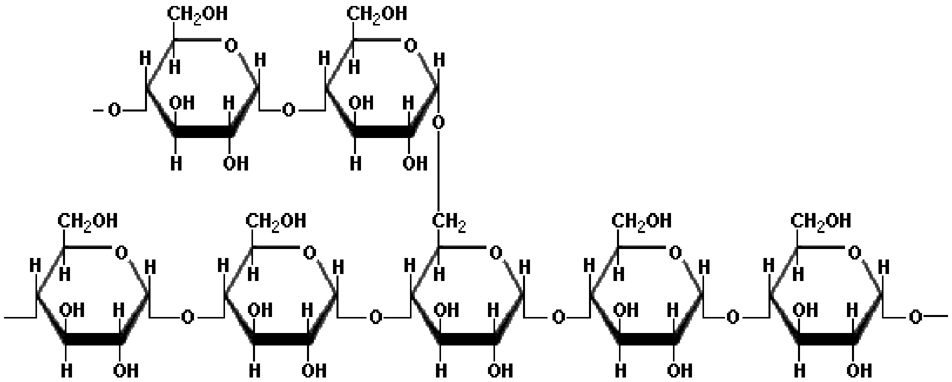
Protein Rest

- Not usually required for well-modified modern malts
- Proteins and polypeptides broken down into amino acids by proteases and peptidases (enzymes)
- Raises the free amino nitrogen (FAN) level
- Occurs at 116-125° F
- FAN is required by yeast for cell growth
- Too much FAN can cause production of fusel alcohols

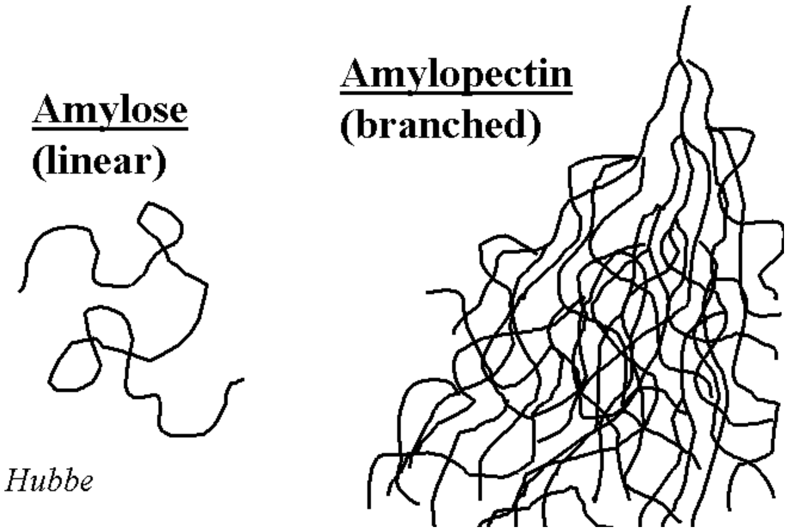


Starch

- Made of amylose and amylopectin
- Glucose units are bound together with two different bonds
- Gelatinizes at 141°



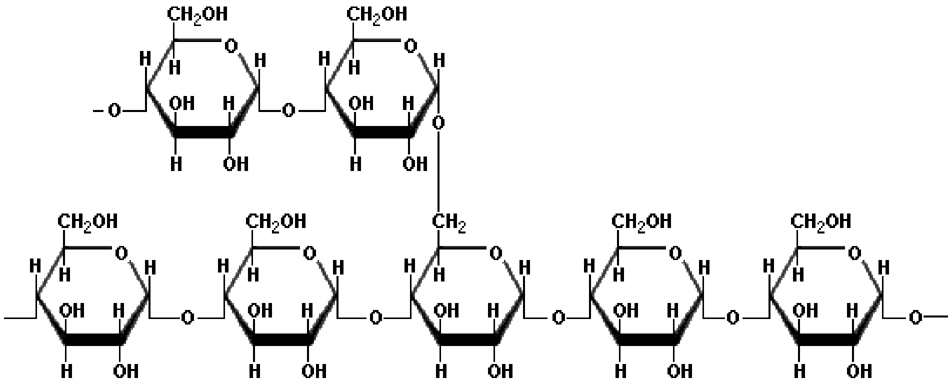
Native Starch Types

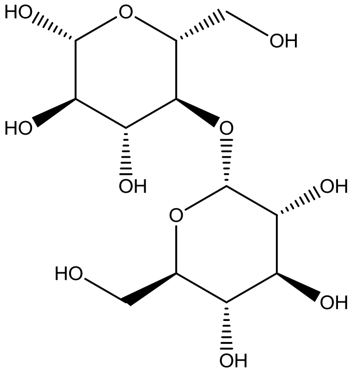


M. Hubbe

Starch breakdown by amylase

- Starch is broken down by two types of amylases α and β.
- α amylase breaks 1-6 links
- β amylase breaks 1-4 links to produce maltose
- β amylase will not break link where 1-6 bond is present

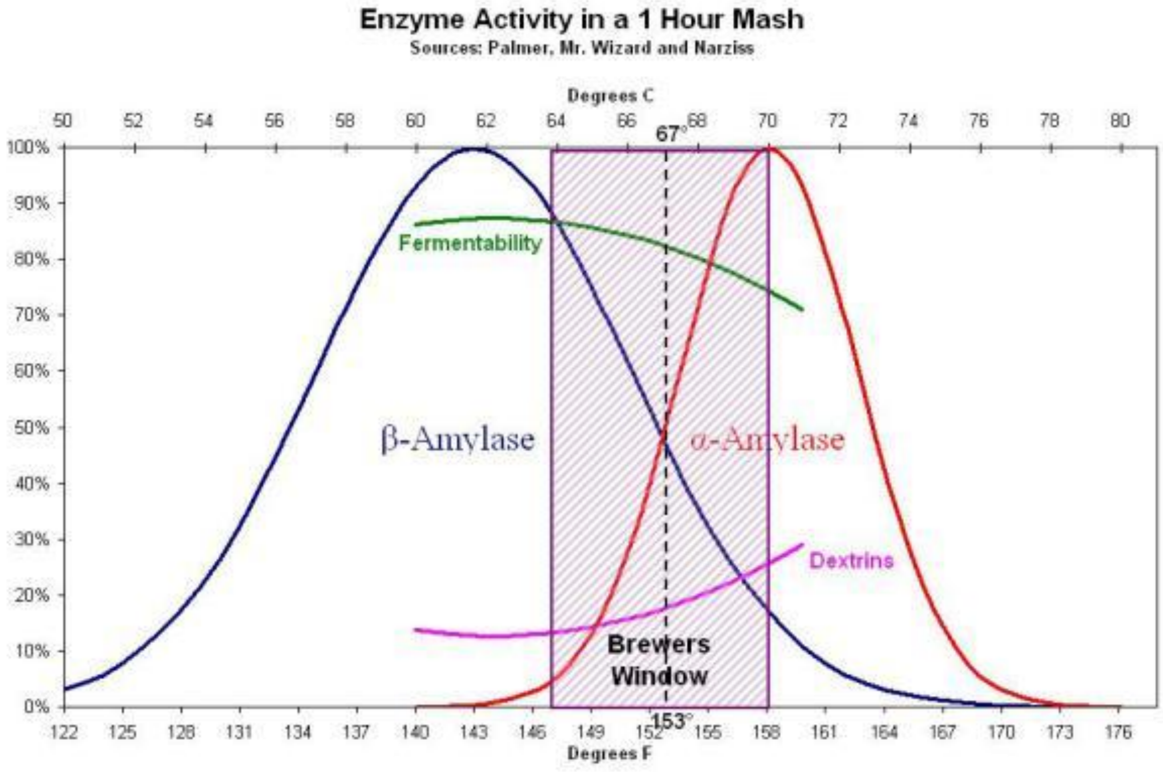




Maltose

Amylase temperature

- High fermentability produces a drier beer
- Low fermentability produces a sweeter beer with higher terminal gravity
- β amylase denatured at 158°

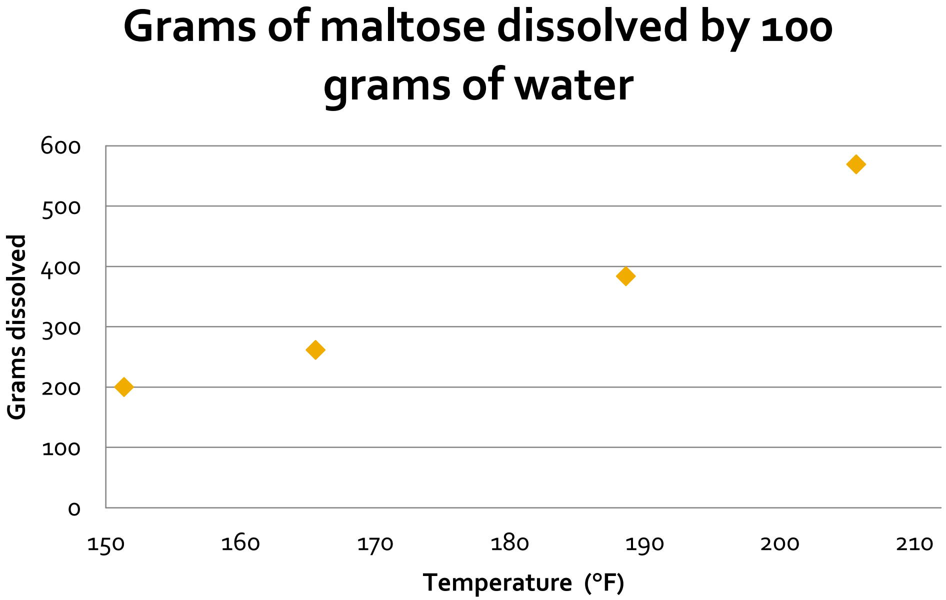


Enzyme Activity in a 1 Hour Mash

Sources: Palmer, Mr. Wizard and Narziss

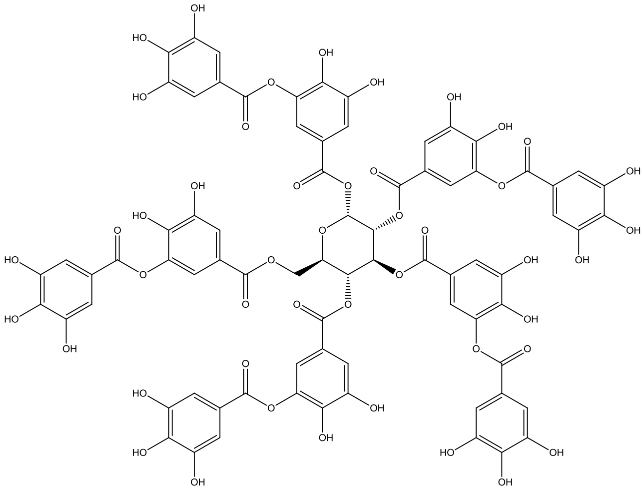
Sugar Solubility

- Hot water holds more sugar than cold water
- Affects efficiency



Phenols during sparging

- Sparging extracts unwanted phenols from grain that add astringency (tannins). Imparts clove, medicinal, plastic, band-aid, electrical fire
- Not very soluble in water, but can become more so
- More related to pH than temperature, but sparge temperature is a factor
- Critical temperature for phenol extraction is 170°
- Optimum sparge temperature is 165-167°



The Boil - Temperature-related chemistry

- DMS formation
- More Maillard reactions
- Hot-side aeration
- Hop isomerization
- Hop oil evaporation
- Protein break
- Haze

DMS Formation

- DMS formation is related to temperature and time
- Forms from S-methyl methionine in malt
- SMM has a half-life of 40 minutes at 212°
- Most DMS evaporates during the boil
- DMS in wort is formed during cooling
- Faster cooling significantly reduces DMS levels in wort
- Fermentation at ambient temperatures reduces DMS level by 50%

More Maillard reactions!

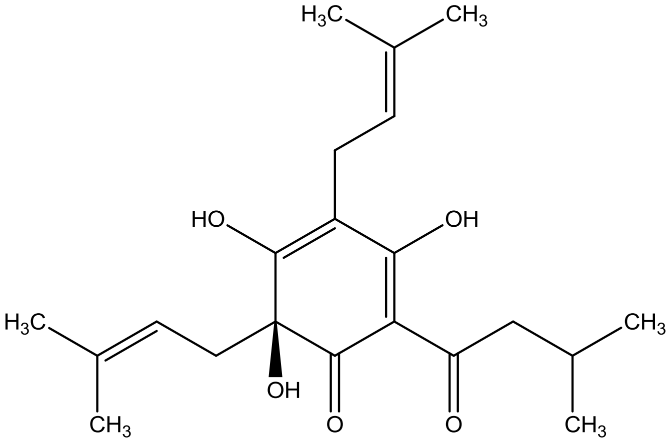
- Maillard reactions during the boil make the wort darker
- Create delicious caramel, nutty flavors
- High-temperature boils can cause undesirable heterocyclics to form (cooked cabbage, sweet corn, vegetal, astringent)

Hot Side Aeration

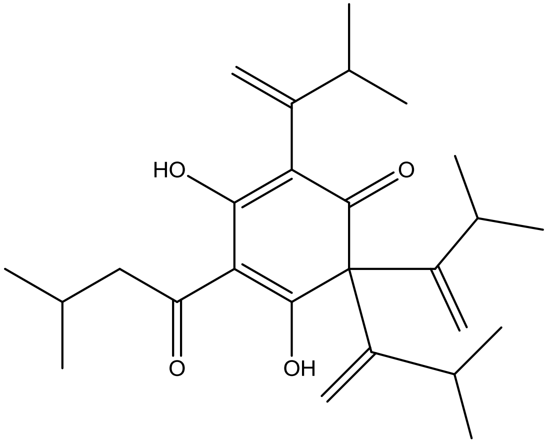
- Oxidation reaction causes cardboard taste
- Melanoidin (Maillard Product) is oxidized in the presence of heat
- Held in check during fermentation and maturation by yeast, then goes to town forming aldehydes
- Other major player: trans-2-nonenal (T-2-N)
- Reduce by more vorlauf/slower sparge for bright clear wort

Hop chemistry overview

- 2 types of acids α and β
- Chemical difference is the OH group attached to the ring
- α acids are not very soluble, but are more soluble when isomerized
- Isomerized α acids inhibit gram-negative bacteria reproduction



alpha acid (humulone)



beta acid (lupulone)

α acid loss

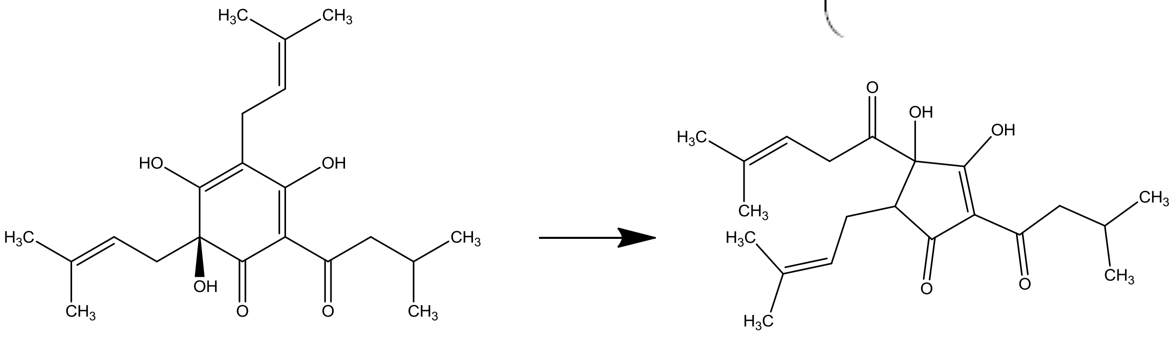
- After harvest, hops begin to loss their alpha acid content. The rate of loss is halved for every 27 ° drop in temperature
- To minimize the amount of alpha acid loss, hops should be stored in a cold, dark place, and in packages that are free of oxygen.
- Some hop varieties store better than others. For example, Cascade hops stored at 68 ° will typically lose 50% of its alpha acids after 6 months storage, while Galena usually will lose only 15% under the same storage conditions

- $At = Ao * e-k*TF*SF*t$

Hop isomerization

- α acids in hops change form to become more soluble, requires heat
- Isomerized cohumulone more soluble than humulone, gives a harsher bitter
- Noble hops (Hallertau, Saaz, Tettnang) have low cohumulone levels

$$IBU = \left(1.65 \times 0.000125^{\left(G_{gravity} - 1\right)}\right) \times \frac{\left(1 - e^{-0.04 \times t_{\min}}\right)}{4.15} \times \left(\frac{\left(\frac{\alpha\%}{100} \times W_{oz} \times 7490\right)}{V_{gallons}}\right)$$

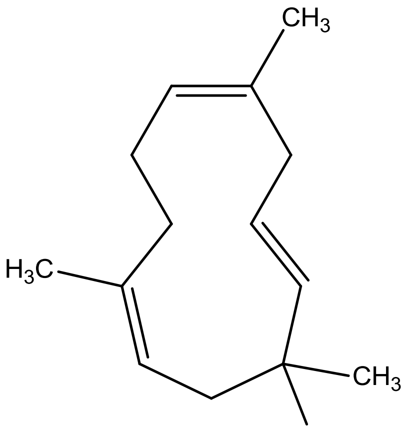


alpha acid (humulone)

Isohumulone

Hop oils are lost during the boil

- The lovely smell during the boil is your hop aroma escaping
- Adding hops near the end of the boil reduces the amount of α acid isomerization and gives the hop oils less time to evaporate
- Related to temperature due to evaporation



Humulene

Breaks

- Two breaks occur – hot and cold
- Hot break is caused by protein coagulation and denaturation, just after the boil starts
  - Lots of foam, causes boilovers
- Cold break happens during chilling
  - Proteins precipitate and drop to the bottom
  - Reduces chill haze

Haze

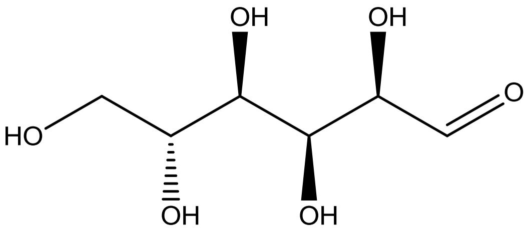
- Haze happens when proteins become less soluble and make beer hazy
- Chill Haze happens when beer gets close to 32°
  - More stable beer (less protein) has a lower chill haze temperature
- Permanent haze happens. Made worse by high temperatures
  - Rule of thumb: 1 week at 100° is equal to a month at 65°

Fermenation

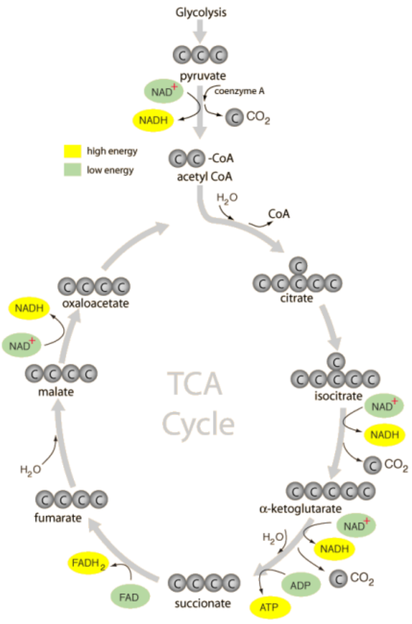
- Overview
- Products
- Byproducts/Off Flavors

Fermentation overview

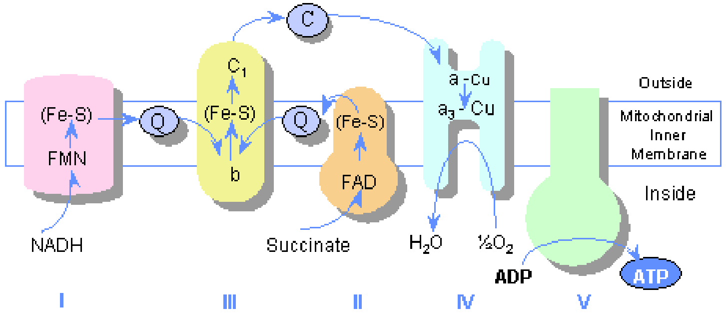
- Yeast turns sugar into energy by removing the hydrogen that is attached to the carbon molecules, producing water, CO2, and energy (ATP)



glucose



Mitochondrial Electron Transport Chain



Anaerobic Digestion

- In the absence of oxygen, the necessary precursors are not formed and the cycle breaks
- Fermentation is a less efficient way of breaking down sugar when no oxygen is present
- Produces CO2, ethanol, and energy

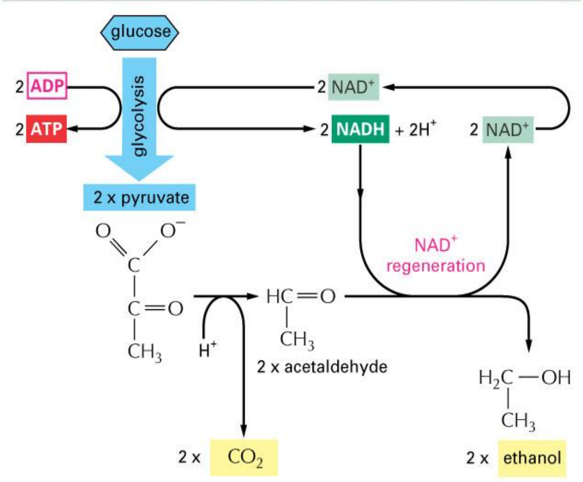
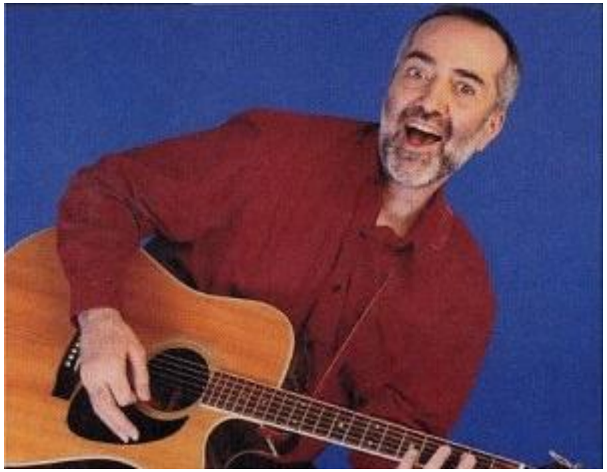


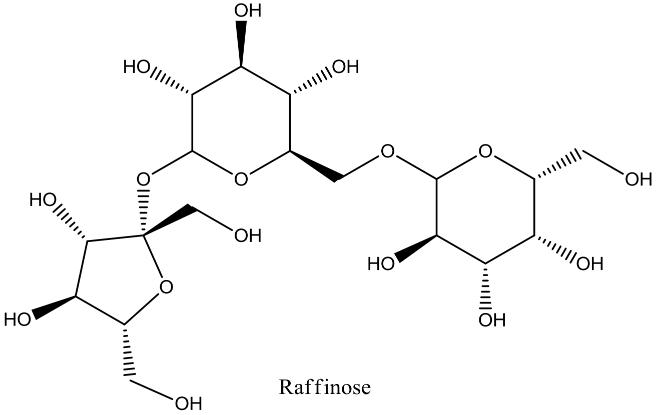
Figure 13-4 part 2 of 2 Essential Cell Biology, 2/e. (© 2004 Garland Science)

Fermentation Temperature

- Lagers *(Saccharomyces uvarum):* 32 to 55°
- Ales *(Saccharomyces cerevisiae):* 50 to 75°

- Rules of thumb, there are exceptions
  - Steam beer uses lager yeast at ale temperatures





Raffinose

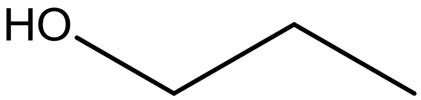
Off flavors related to temperature

- Fusel
- Astringent (Already covered)
- Diacetyl
- DMS (Already covered)
- Ester
- Phenolic (Already covered)
- Sulphur

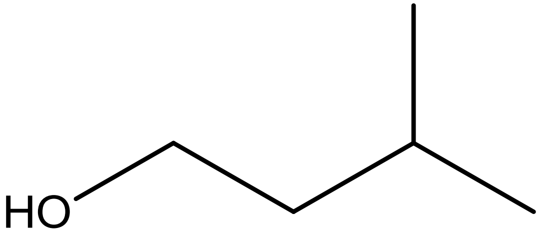
- Dependent on yeast strain

Fusel alcohols

- Hot, spicy, solventlike
- Produced by high fermentation temperatures
- Avoid by using the right yeast strain and control fermentation temperature



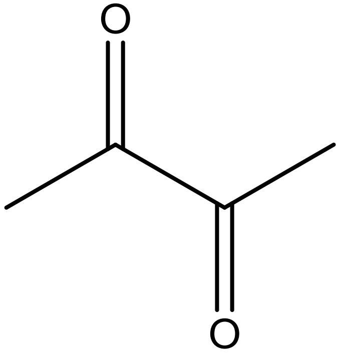
propanol (disagreeable alcohol)



isoamyl alcohol (bananas, solvent)

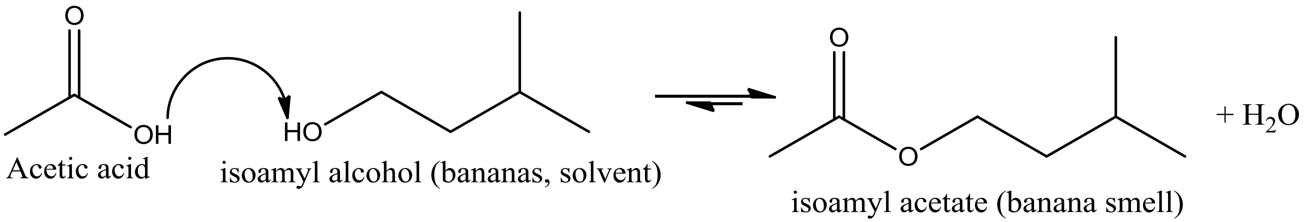
Diacetyl

- Butter or butterscotch
- Produced during normal fermentation, and converted to 2,3-butanediol (which has no flavor or smell)
- Incomplete reduction caused by weak yeast
- Warmer fermentation reduces the amount of diacetyl by increasing yeast metabolism
- Diacetyl rest used in lagering



Esters

- Banana, grapefruit, raspberry, pear, apple, strawberry
- Desired in certain styles
- Acetylaldehyde oxidizes to acetic acid and reacts with alcohols to produce esters
- Ester formation is directly related to high fermentation temperatures



Sulphur

- Rotten eggs, burnt match
- Hydrogen sulfide is produced by yeast during fermentation, usually carried away with the CO_2
- High levels are almost always caused by bacterial infection, but can also be caused by overpitching or an inappropriate temperature for your strain

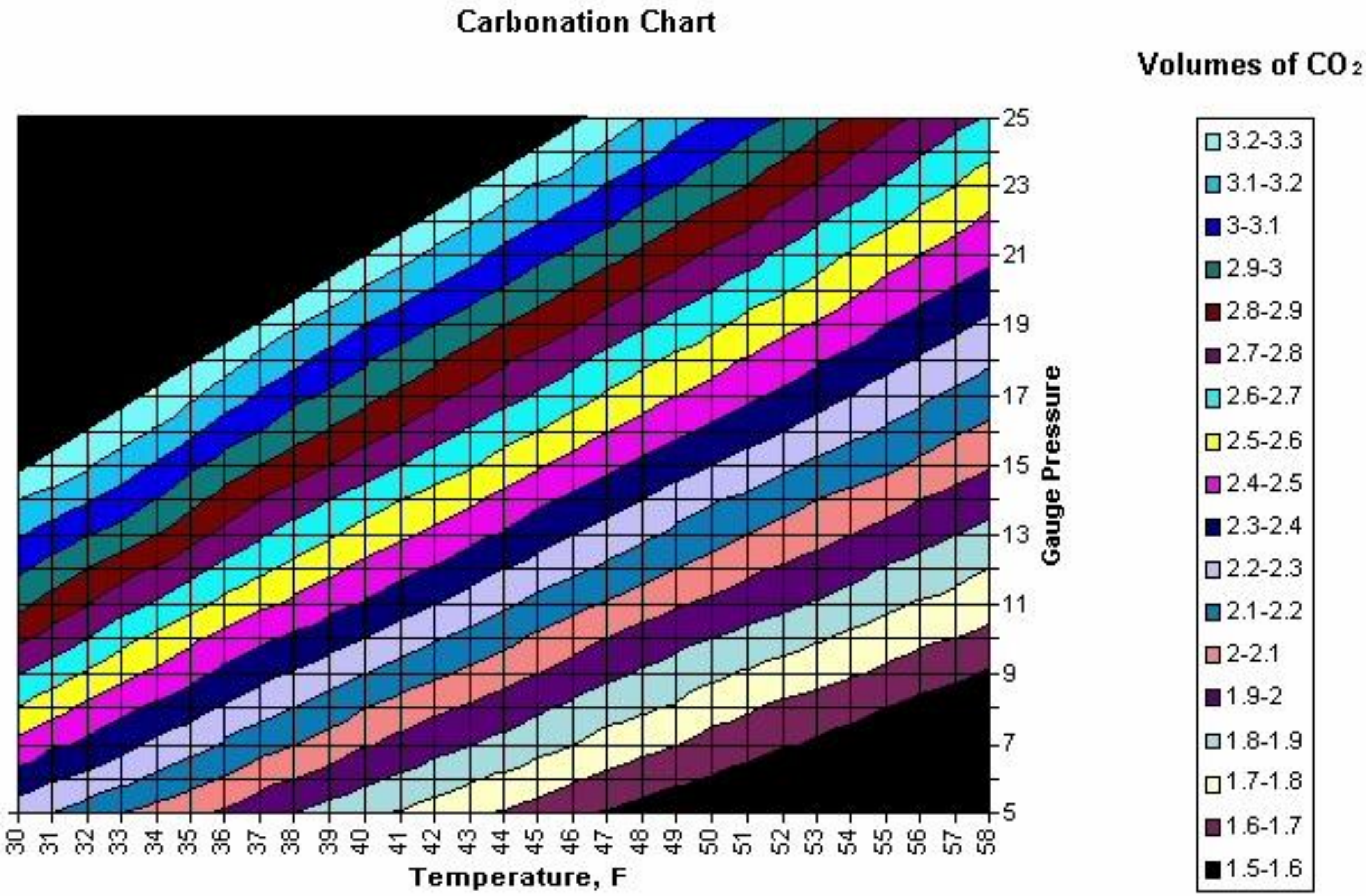
CO2

- Beer is carbonated by exposure to pressurized CO2, either in a keg or in bottles
- Carbonation level is measured in volumes
- 1 volume = 1 L of CO2 per liter of beer at STP
- Works out to 0.0444 mol CO2 per liter (1.95 g)

Beer Style	**Volumes of CO2 Range**
British Ales	1.5 - 2.0
Poter & Stout	1.7 - 2.3
American Ales and Lagers	2.2 - 2.7
European Lagers	2.2 - 2.7
German Wheat Beers	3.3 - 4.5
Belgian Ales	1.9 - 2.4
Lambic	2.4 - 2.8
Fruit Lambic	3.0 - 4.5

CO_2 solubility

- Related to temperature, pressure
- Ideal gas law: $PV=nRT$
- Pressure and temperature are directly related
- The gas in your CO_2 tank is no exception, shows less psi when cold
- CO_2 in beer or in a gas under pressure is trying to escape
  - Higher temperature means the CO_2 is trying harder to escape
  - Lower the temperature, and the beer holds more carbonation


Carbonation Chart
Volumes of CO₂
3.2-3.3
3.1-3.2
3-3.1
2.9-3
2.8-2.9
2.7-2.8
2.6-2.7
2.5-2.6
2.4-2.5
2.3-2.4
2.2-2.3
2.1-2.2
2-2.1
1.9-2
1.8-1.9
1.7-1.8
1.6-1.7
1.5-1.6
Gauge Pressure
25
23
21
19
17
15
13
11
9
7
5
Temperature, F
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58

Time to wake up, he's finally done

- Recap: Temperature is important
- For BJCP members: This talk was worth CEP points

- Next month I'll be talking about yeast propagation, culturing yeast from wild yeast, or from a sample
- I'll also be giving out pitchable amounts of Belgian yeast harvested from the Westvleteren strain, cultured on Petri dishes, and propagated from a single colony
    - This yeast will be used for the September Style Competition, Belgian Strong Ales (single strain)

March Style Competition Program

- Beers were brewed using the same recipe and yeast strain. Temperature was left up to the individual
- Go taste the beer that people brought and look at the sheets to see what differences you can taste and identify
- Thanks to everyone who participated