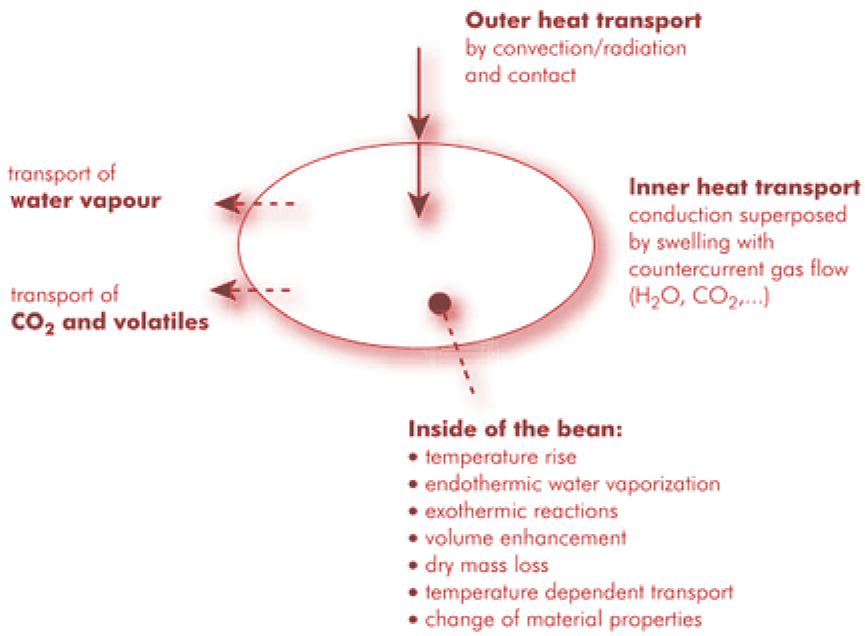
# The Science of Coffee Roasting

Roasting = manipulating chemical and physical reactions




## Types of heat transfer

**Convective** (~70%) – beans transfer heat to each other through air (fan bake).
**Conductive** (~30%)– beans touching a hot surface (eg. the drum wall). This is how beans are heated during the first phase of the roast (frying pan). If there is too much conduction in the early phase, the exterior of the beans can be scorched by sudden hot contact with the drum.
**Radiant** – heat radiating off the cast iron roaster (this is hard to control, we just need to make sure that the roaster is hot enough in the pre-heating phase)
*Fan on drum door as example*

The amount of each type of heat transfer that occurs can be influenced by: airflow, drum speed, burner, batch size

**Endothermic** – heat is being transferred into the bean from outside

**Exothermic** – heat (usually in the form of moisture) is escaping/exploding from the bean into the air

# Phases of the roast

“Like cooking an onion”

**Drying -** the preparation phase

-cold beans become hot

-turning point as a checkpoint that everything is going well, eg. is my batch size correct?

-easy to make corrections in this phase: it becomes harder to do so as the roast goes on

-beans sweat (release and evaporation of surface moisture)

-loss of colour= chlorophyll breaking down

-endothermic heat transfer

-beans move from approx 10% moisture to 2% moisture

-risk of ‘channeling’ as moisture leaves the beans, just like in an espresso puck

**Maillard (from 140-150 degrees C) -** the flavour phases

-need to have declining RoR in order to protect the beans and slow the reactions

-series of cascading reactions

-reducing sugars and amino acids combine to create a soup of reactions creating new molecules

-smells like food (pasta, bread)

**Strecker Degradation -** complexity and volatile aroma

-amino acids react with compounds created by maillard reactions creating aldehydes

-aldehydes are volatile compounds with distinct aromas

-byproduct of strecker degradation is C02

**Caramelisation (from approx 170 degrees C)**

-caramelisation and maillard can overlap

-literal caramel-like flavours

-pyrolysis = burning of sugar - this is positive but can result in burning if goes too far

-complex carbohydrates are broken down into simple sugars like fructose and glucose that can dissolve in water

-want to preserve some acidity – staying too long in this phase can make a coffee boring

**First Crack – water escaping to produce steam**

-pressure building inside the bean, which causes an explosion

-endothermic to exothermic heat transfer

-sounds like popcorn

-change of aroma and bean structure

-always be consistent when marking roast events

-release of moisture into environment

**Ending the roast**

-decide the end of roast based on: how much energy have you given the beans? Do they have momentum?

-how even is the coffee (uniformity of green coffee and length of roast thus far)?

-how dense is the coffee?

-what type of cup are you aiming for?

**(Second Crack) - Co2 escaping from bean's core**

-sounds like rice krispies

-metaphor: a log burning on the fire– it sparks and cracks loudly once, then, after a while, begins to actually break down

# Chemical changes in the roasting process

## Maillard reactions: the result of sugar and protein being heated together

Impacts: body, viscosity, colour change

Occurs from 140-150°C→

The reaction requires a relatively high temperature and for sufficient moisture to have disappeared from the bean. This is why it doesn't begin until after the 'drying phase'

*The chemistry of maillard:*

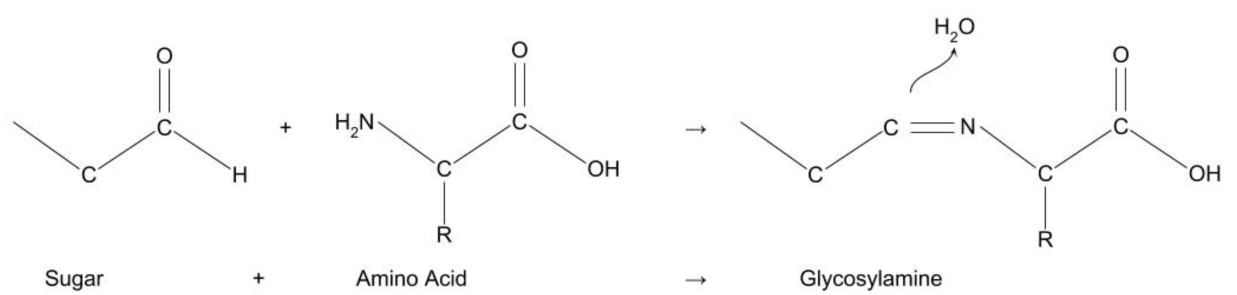
-non-enzymatic reaction (ie. it turns things brown without the use of enzymes)

**-reaction occurs between a 'reducing sugar' and amino acids**

A reducing sugar is any sugar (carbohydrate) that has a free aldehyde or ketone group. These bond easily with amino acids.

Amino acids are the building-blocks of proteins

Amino acids will bond with reducing sugars to produce glycosylamine.




Glycosylamine is unstable and it will change structure into caramel-like molecules or short-chain molecules (diacetyl).

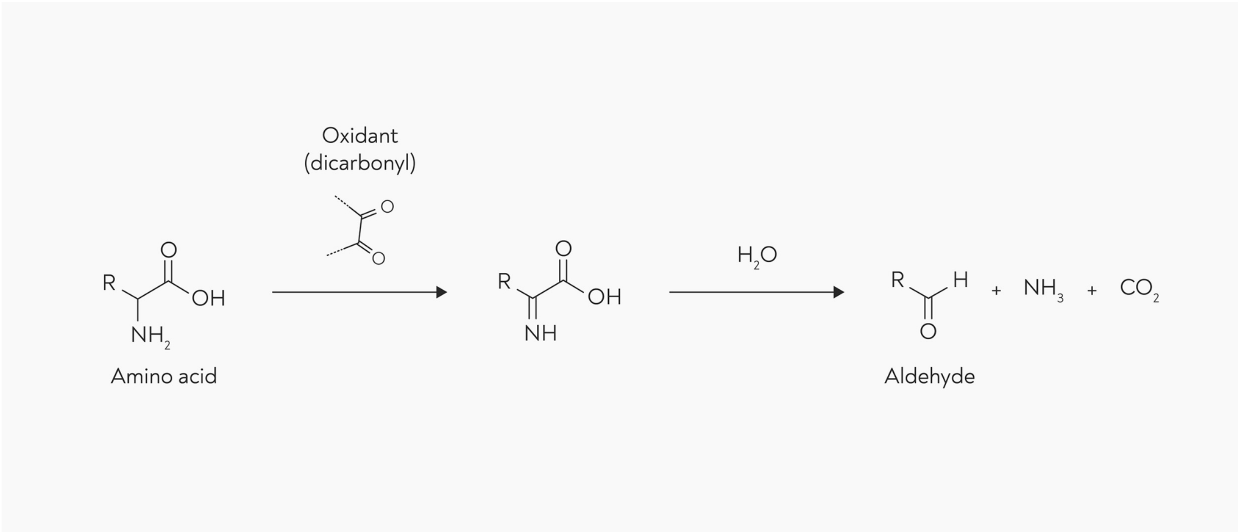
These caramel-like and diacetyl molecules then transform into melanoidins.

These are large molecules that not only turn the beans brown, but contribute to mouthfeel and body. They are non-volatile, meaning that they stay stable within roasted coffee, even when cupped. **A coffee's amino acid content is closely related to its quality. The more amino acids, the more reactions and the more melanoidins.**

## Strecker Degradation: a subset of the maillard reactions that has a big impact on flavour and aroma

A process where amino acids react with compounds created during the maillard reaction to form melanoids and volatile aromatic compounds
Impacts: $CO_2$, aroma
Occurs from 160°C→

Strecker degradation is a two step reaction: the amino acid is oxidised with the help of another compound (the oxidant), and the resulting molecule then breaks down into an aldehyde, giving off ammonia and carbon dioxide in the process.




Aldehydes have very distinctive aromas. They are very important to the flavour and aroma of roasted coffee. They are volatile aromatic compounds, which means they will gradually disappear after grinding, or as a coffee rests.
Strecker Degradation helps advance maillard reactions and make the coffee flavoursome and delicate, not just brown and sweet. If a roast goes on for too long, or reaches particularly high temperatures, aldehydes will start to be destroyed.
Each amino acid that is broken down during this phase produces a single molecule of carbon dioxide. The $CO_2$ produced during Strecker Degradation is responsible for approximately 80% of the total $CO_2$ in the bean. These $CO_2$ molecules are stored in the core of the bean and will usually be released over several days or weeks. If you roast for too long, this $CO_2$ will explode outwards, causing second crack.

## Caramelisation: the pyrolysis of sugars

Complex carbohydrates break down into smaller sugar molecules that can be dissolved in water.
Impacts: $CO_2$, aroma
Occurs from 170°C→

This is separate to the maillard reactions.
Pyrolysis= thermal decomposition. This occurs until the end of the roast and can result in burnt flavours (or even beans turning into carbon) when it goes too far.
Complex carbohydrates are broken down into simple sugars (monosaccharides) like fructose and glucose
Carbohydrates make up “approximately 50% of coffee’s total dry basis”. These include sucrose, arabinose, mannose, glucose, galactose, rhamnose and xylose. Of course, not all of these sugars are soluble in water. Only a certain percentage will end up in your cup.

# Acid break-down

| COMPOUND | SENSORY IMPACT | IMPACT OF ROASTING |
|---|---|---|
| **Citric Acid** | **Sour flavor, lemon- or lime-like.** | Concentration decreases during roasting starting around 176°C. |
| **Malic Acid** | **Tart flavor, green apple-like** | Concentration decreases during roasting starting around 190°C. |
| **Quinic Acid** | **Bitter flavor, cranberry-like, astringent, dry mouthfeel** | Concentration roughly doubles during roasting as a result of chlorogenic acids breaking down. |
| **Caffeic Acid** | **Intense bitterness** | Concentration increases during roasting as a result of chlorogenic acids breaking down. |
| **Acetic Acid** | **Main acid in vinegar, vinegar- or wine-like** | Created during the roasting process as sugars and broken down. Concentration continues to increase throughout roasting, up to 240°C. |
| **Chlorogenic Acid** | **‘Green’ flavours, (chlorogenic acid is also found in tobacco leaves)** | As coffee is roasted darker chlorogenic acids will split into caffeic and quinic acids, increasing bitterness. |

-Citric and malic acids are naturally present in green coffee and are gradually broken down during roasting
-Chlorogenic acids become quinic and caffeic acid. Chlorogenic acids constitute approximately 6-8% of the weight of green Arabica coffee and approximately 10% of green Robusta. On the coffee tree chlorogenic acids help to immobilize toxic caffeine molecules so that they do not cause harm to the plant itself.

-Organic acids are related to good acidity, which is a crucial attribute of quality correlated with sweetness. Arabica coffee is more acidic than Robusta, and a coffee's acidity decreases with roasting. Dark roasts decrease a coffee's acidic content and perceived acidity.

## Physical changes in the roasting process


*Green coffee interior cell wall*

Anatomy of a coffee bean essential to how it roasts. If you grind up green coffee and subject it to the same temperature, etc, you don't get the same results
Bean acts as a minireactor or a pressure cooker, in which chemical reactions can occur. The physical structure of the bean and the changes that it goes through, create the right environment for chemical changes to occur in a certain sequence.

Coffee beans have some of the strongest cell walls in the plant kingdom. These are reinforced by external rings
As coffee is heated, the transformation of water into gas creates extremely high pressure. This causes the structure to turn from rigid to rubbery (if you bite into a bean when it's still hot, it will feel rubbery)
"The internal matter pushes out towards the cell walls, leaving a gas-filled void in the center. This means that the beans expand in volume as they decline in mass. Much of the gas build-up is carbon dioxide that will be released after the roast."

| Bean temperature (°C) | Effect |
|---|---|
| 20 - 130 | Moisture evaporates and dries up the bean. Colour fades |
| 130 - 140 | First endothermic reaction. Yellowing in colour, swelling of the bean and starting the Maillard reaction. Roast gases are formed and begin to evaporate. |
| 140 - 160 | Complex series of endothermic and exothermic peaks. Beans colouring to light brown. A large increase in bean volume and micropores. Silverskins are removed. Bean is becoming very brittle. The surface of the bean starts cracking. Aroma formation starts. |
| 160 - 190 | Roast reactions move toward the inner, dry structure of the bean. |
| 190 - 220 | Small cracks inside the bean. Smoke and large volumes of carbon dioxide escape and leave the bean very porous. The typical roasted coffee flavours are formed. |

## Oil/Lipid migration

Lipids, or oils help to trap volatile aromas inside the cells and preserve aromatic compounds, such as aldehydes. Lipids will migrate from the bean cells to the exterior of the bean during roasting, particularly after second crack. If too many lipids move to the exterior this will reduce complexity and result in faster aging of the roasted bean. This process occurs more frequently in decaffeinated coffees, as their additional processing has reduced the strength and integrity of the bean's cell walls.

# Volatile and non-volatile compounds

**Volatile compounds**– have high vapour pressure at room temperature.
Are released powerfully but can dissipate quickly

Aldehydes, which add fruity, green aromas.
Furans, which contribute caramel odors
Pyrazines, which have an earthy scent.
Sulfur-containing compounds, including 2-furfurylthiol. Some of these have an aroma that is commonly described as “roasted coffee” but there are others that don’t smell as appealing in isolation. For example, methanethiol smells like rotten cabbage.
Guaiacol, which has smoky, spicy tones.

There are over 1000 volatile compounds in coffee, but only 20-30 contribute to flavour (or at least flavour that humans can perceive).

| COMPOUND | TYPE | AROMA / FLAVOR QUALITY |
| --- | --- | --- |
| Furaneol | Furan | Sweet, caramel |
| Acetaldehyde | Aldehyde | Pungent, fruity |
| Methylpropanal | Aldehyde | Floral, spicy |
| 2,3-pentanedione | Diketone | Buttery |

**Non-volatile compounds** – stable at room temperature
Caffeine is naturally occurring in coffee and remains unchanged by the roasting process. Other non-volatile compounds include sucrose, which provides sweetness, and lipids, which provide body and mouthfeel. The melanoidins that create color and body are also non-volatile compounds.