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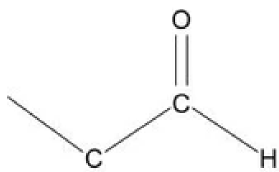
The Maillard Reaction

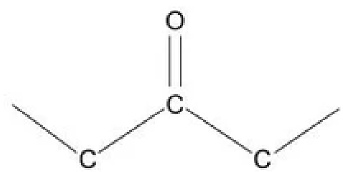
The Maillard reaction is a reaction that nearly every cook uses to make their food taste good. This is often described as caramelization or the “browning” of foods. More specifically, this is a chemical reaction between the food’s amino acids and reducing sugars. This reaction leads to the distinctive flavors of seared meat, fried potstickers, bread, toasted marshmallows, and many more. This reaction was initially described by French chemist Louis Camille Maillard in 1912 while attempting to reproduce protein synthesis. This discovery leads to further discussions in the food sciences about the said reaction.

The Food Lab describes the reaction as “many small simultaneous chemical reactions that occur when the proteins and sugars in and on your food are transformed by heat, producing new flavors, aromas, and colors.” The strength of this reaction is often based on the food itself. Each food has a different ratio of protein, sugar, and water. A steak, for example, is a muscle, which is mostly protein and water with little sugar. This high protein concentration leads to a Maillard reaction that yields more flavor molecules and less aromatic ones. In contrast, a cookie is mostly sugar. This high concentration of sugar leads to a Maillard reaction that yields more aromatic molecules than flavor ones.

In the Maillard Reaction precisely, the kinetics can be described as the time and temperature necessary to cause the reaction. For coffee beans, this reaction occurs between 280ºF and 330ºF. Within this 50º range, the Maillard reaction can create hundreds of new flavors. Specifically, this makes the roast-y and malty flavors that many enjoy daily. This flavor breakdown happens due to reducing sugars and amino acids. A "reducing sugar" is any sugar that has a free aldehyde group or ketone group. An aldehyde is just any chemical compound that contains a carbonyl center bonded with a Hydrogen atom. A ketone group is any chemical compound with a carbonyl center with two carbon-containing substituents—examples of both are shown below.



Aldehyde group



Ketone group

Kinetics for the Maillard reaction is vital because any difference in temperature or time can lead to a different outcome. Examples of such include the roast level of coffee. The kinetics of a light roast consists of a lower temperature for a lower time. This leads to a more hydrated bean with a more acidic taste. This differs from a dark roast, which consists of a higher temperature roast for a longer time. This leads to a more dehydrated bean with a concentrated, caramelized taste. These different outcomes exemplify the difference in kinetics. The different temperatures and durations have led to a completely different end product.

The kinetics can lead to the Amadori rearrangement. This is an organic reaction that describes the typical non-enzymatic carbohydrate modification. For the Maillard reaction, in particular, Aldose and amino compounds react twice to create Amadori and fission products. This is the origin of the browned flavor that many people strive for. Sugars and amino acids react with a high temperature to create a Schiff base. This base is a subclass of imines, which is either a secondary aldehyde or secondary ketimine. Schiff bases are aldehydes or ketone compounds where an imine group has replaced the carbonyl group. The Schiff base then reacts again with high temperature to create an Amadori adduct. This adduct then goes through a dehydration process. The amount of time of this process is determined by the kinetics of the process. An increased temperature would decrease the time required for dehydration. After the dehydration process, the products go through an Aldol condensation to create melanoidins. These melanoidins are the leading cause of the different aroma and signature browned color.

All of this ties in with the thermodynamics of the reaction itself. The Maillard reaction Utilizes the Second Law of Thermodynamics to flourish. The law states that heat flows in one direction, from a warmer system/environment to a colder system/environment. Many factors play into the speed of this reaction, primarily the kinetics of the reaction itself—the more significant the temperature difference, the quicker the heat transfer. The longer the systems are in contact, the longer the heat has to shift systems and create an equilibrium.

This law is most prominent in the roasting of the coffee bean itself. When a coffee bean is inside a roaster, the heat in the environment and the system are taken into account when creating a roast. While being roasted, the coffee bean begins an endothermic phase, where the bean absorbs heat from the roaster environment. While this is happening, H_2O and CO_2 are being released from the environment. Inside the coffee bean itself, the internal temperature increases, there is dry mass loss, increased volume, water vaporization, and sugar browning. Once the internal temperature of the coffee bean reaches 160ºC, the Maillard reaction signifies the gradual move of an endothermic to an exothermic reaction. However, once the internal temperature reaches 175ºC, the reaction becomes formally exothermic, as the internal temperature becomes greater than its environment.

The nitrogen within the amino acid bonds to the carbon chain gives off one single molecule of water. This changes the structure of the chain then reacts again into one of three compounds: a compound that loses more water molecules to create caramel molecules, break down into shorter chain molecules like diacetyl to develop foods with a buttery flavor, or break down into more amino acids. Each of these reactions can further break down into molecules named melanoidins. These molecules are known for their "roasted, amity, bready, bitter, and burned flavors." While the coffee bean is being roasted, the change in the internal energy of the roasting system is the sum of the entering heat and the heat being created from the Maillard reaction. As the sugars break down, more heat is added to the system internally. This leads to an internal pressure buildup that then signifies the beginning of the exothermic reaction. This pressure build-up then cracks the bean, which indicates the climax of the exothermic reaction.

The Maillard reaction relies on kinetics and thermodynamics to host itself. Mainly, the thermodynamics occur in the coffee bean's roasting, and the kinetics describe the duration and temperature of the roasting environment. These different values can either complement or conflict with each other. In the cases in which they are complementary, the temperature of the roaster is high enough to allow the Maillard reaction to occur and left in there long enough to allow the sugars to caramelize deeply. However, if the temperature is too high and the time inside the roaster is too low, there is not enough time for the heat to travel throughout the entire coffee bean, and the intense heat will burn just the exterior while the inside is still "raw." A proper balance is required to create the desirable flavors of dark roasted coffee.

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