Why Do We Cook Our Food and What Happens When We Do?

08 November 2010

Cooking review

Part 1: Introduction

At present, conclusive evidence eludes us as to the origins of cooking. Some researchers believe that cooking was invented over 2.3 million years ago, whilst others argue it is a more recent concept, being invented only 40,000 years ago. Despite these opposing views, it is clear that cooking has been around for a long time and continues today to play a fundamental role in daily life across the globe. Cooking was first used for preservation but it has evolved and now it is a form of entertainment and creativity for many people. Currently using the search term "cooking" in Google produces a search result containing over 40 million blog posts and news alerts. These include articles ranging from cooking recipes and creative cooking classes to games using a cooking theme as a platform.

What is cooking?

Cooking is the process of producing safe and edible food by preparing and combining ingredients, and (in most cases) applying heat. Cooking is a means of processing food, without which many foods would be unfit for human consumption.

1. Why do we cook food?

1.1. Safety

Raw foods such as meat, fish and eggs, may harbour food poisoning bacteria, which if consumed are likely to cause illness. The optimum temperature for the multiplication of most food poisoning bacteria is between 5 - 63°C, whilst, at temperatures over 70°C most bacteria are killed and below 5°C most food poisoning bacteria can only multiply slowly or not at all. Most cooking methods if performed properly will heat foods to over 70 °C, so applying such a temperature for a carefully calculated time period (along with correct food preparation and storage procedures) will prevent many food borne illnesses that would otherwise manifest if the raw food was eaten.

Campylobacter, Salmonella and Listeria monocytogenes are three of the most common food poisoning bacteria and together are reported to affect over 380,000 European Union (EU) citizens each year. Table 1 lists the foods these bacteria are most likely to be found in and the symptoms they commonly cause.

Table 1: Common food poisoning bacteria and their likely food sources and symptoms

Bacteria	Most likely food sources	Symptoms
Campylobacter	Raw poultry and meat, unpasteurised	Fever, headache, diarrhoea

	milk	
Salmonella	Raw meat, poultry and eggs, raw unwashed vegetables, unpasteurised milk and dairy products	Fever, diarrhoea, vomiting, abdominal pain
Listeria monocytogenes	Raw milk, meat, poultry, cheeses (particularly soft, mould-ripened varieties), salad vegetables	Flu-like symptoms, meningitis, septicemia and, in pregnant women, abortion, miscarriage

1. 2. Digestibility

The fundamental reason we consume food is to extract the vital nutrients that different foods contain to allow our bodies to function properly. This is achieved by digestion, where foods are broken down in the body into a form that can be readily absorbed. However, many of the nutrients contained in foods are not readily accessible prior to cooking and thus, cannot be easily digested by the body. For example, the enzyme amylase (found in the mouth and intestine) breaks down the polysaccharide starch into its monomer glucose constituents, which can easily be digested by the body. Cooking foods containing starch (e.g., cereals and vegetables), prior to consumption initiates the breakdown of the polysaccharide, thus, aiding the action of amylase and the consequent digestibility of the carbohydrate component of the food.

A further discussion of starch degradation can be found later in the review under the heading 'what happens to food when it's cooked?

1. 3. Edibility

The desire to eat is primarily driven by the body's need for nutrition, with the intake of essential nutrients being indispensable for life. This fundamental reason to eat is challenged by the psychological needs of enjoyment and pleasure. Cooking can cause changes in the colour, flavour and texture of foods that allow us to create foods that we derive pleasure from eating. For example, roasting potatoes initiates a series of changes that makes them edible, as well as attractive in colour and taste by generating a golden brown colour, invoking a natural sweetness and producing a crisp shell and a soft internal texture.

For many foods, the cooking process gives them the characteristics we associate with edible food, which are generated through an intricate series of physical and chemical changes that occur when foods are heated. Therefore, without cooking, these changes could not occur and many foods would be deemed inedible.

A detailed discussion of these changes can be found later in the review under the heading 'what happens to food when it's cooked?

2. What are the main types of cooking?

The fundamental types of cooking from which cooking methods stem across Europe and indeed, the world, are listed below.

2. 1. Frying

Frying is the cooking of food in oil or fat. Usually, foods that have been fried have a characteristic crisp texture. This is because oils and fats can reach higher cooking temperatures than water, which results in the food being seared. Common types of foods that are fried include; battered or breaded fish or vegetables, crisps, chips and doughnuts.

There are several different types of frying, which vary by the amount of fat / oil required, the cooking time and the type of cooking pan:

- Stir-frying – a frying pan or wok is used to cook foods at a very high temperature, in a thin layer of fat. The food is fried very quickly, during which time it is stirred continuously to prevent the food from burning.
- Deep-frying – a large, deep pan, or deep-fat fryer is half-filled with fat and heated. Food is immersed in the fat for a few minutes, then removed from the fat and drained.
- Shallow-frying – a large, shallow pan is filled with a layer of fat deep enough to cover about one third of each piece of food to be fried. As with deep-frying, the fat is heated prior to the food being added to the pan. After a few minutes cooking, the food is removed from the pan and drained.

Different types of cooking fats/oils for different uses

In general, cooking is carried out in an aqueous environment whereas frying is carried out in oils. In this section, we will focus on the frying performance of common fats and oils as different types of oils are not equally suitable for frying. The choice of oil used in frying depends on taste and on heat stability. Some oils are heat-resistant and can be used at high temperatures, while others with intense flavours and lower heat resistance are best enjoyed raw in salad dressing for example.

When heated, fats are modified by the combination of the oxygen in the air and the increasing temperature. The most visible modifications are an increase of the coloration (browning) and the viscosity, the apparition of foam and the formation of off-flavours. The smoke point of an oil or fat is the temperature at which it gives off smoke. The smoke point generally refers to the temperature at which a cooking fat or oil begins to break down to glycerol and free fatty acids.

Based on their composition, two groups of fats can be defined: saturated and unsaturated fats. Saturated fats are mainly animal fats (e.g. butter, lard) and are solid at room temperature. Some plants fats are also high in saturated fats such as coconut oil and to a lesser extent palm oils. Saturated fats offer a higher temperature and oxidation stability than oils with a high content of unsaturated fatty acids. However, saturated fats are more likely to produce smoke and foam when heated.

Unsaturated oils are found both in animal and plant products. There are two types of fatty acids: monounsaturated and polyunsaturated fatty acids. Properties depend on the precise fatty acid composition. Monounsaturated fatty acids occur abundantly in oils like olive, peanut, and canola/rapeseed. They are liquid at room temperature. Polyunsaturated fatty acids occur at a high level in oils like corn, safflower, sunflower, soybean, cotton seed, and sesame seed oils. They are also liquid at room temperature.

Trans fats are produced when liquid oil is made into a solid fat by a process called hydrogenation. In recent years they have been removed largely from frying oils and fats because of their negative health properties. For health reasons, the ideal cooking oil should contain high amounts of monounsaturated and polyunsaturated fats, with low amounts of or no saturated fats and trans fats as well as a smoke point higher than the cooking temperature (see Table 2).

Table 2: Suitable cooking uses of fats and oils

Fats or Oils	Cooking Uses	Type of Fat	Smoke Point °F	Smoke Point °C
Almond Oil	Sautéing, stir fry	Monounsaturated	420°F	216°C
Butter	Baking, cooking	Saturated	350°F	177°C
Butter (Ghee), clarified	Frying, sautéing	Saturated	375-485°F (depending on purity)	190-250°C (depending on purity),
Canola Oil (Rapeseed oil)	Good all-purpose oil. Salad dressing and cooking.	Monounsaturated	400°F	204°C
Coconut Oil	Coatings, confectionary, shortening	Saturated	350°F	177°C
Corn Oil	Frying, salad dressings, shortening	Polyunsaturated	450°F	232°C
Cottonseed Oil	Margarine, salad dressings, shortening, frying.	Polyunsaturated	420°F	216°C
Grapeseed Oil	Sautéing, frying, salad dressings.	Polyunsaturated	392°F	200°C
Hazelnut Oil	Salad dressings, marinades and baked goods.	Monounsaturated	430°F	221°C
Lard	Baking and frying	Saturated	370°F	182 °C
Olive Oil	Cooking, salad dressings, sautéing, pan frying, searing, deep frying, stir frying, grilling, broiling, baking	Monounsaturated	Extra Virgin - 320°F Virgin - 420°F Pomace - 460°F Extra Light - 468°F	160°C 216°C 238°C 242°C
Palm Oil	Cooking, flavouring	Saturated	446°F	230°C
Peanut Oil	Frying, cooking, salad dressings	Monounsaturated	450°F	232°C

Sesame Oil	Cooking, salad dressings	Polyunsaturated	410°F	232°C
Shortening, Vegetable	Baking, frying	Saturated	360°F	182 °C
Sunflower Oil	Cooking, margarine, salad dressings, shortening	Polyunsaturated	450°F	232°C
Vegetable Oil	Cooking, salad dressings	Polyunsaturated		
Walnut Oil	Sautéing, pan frying, searing, deep frying, stir frying, grilling, broiling	Monounsaturated	400°F	204°C

2.2 Baking

Baking is the process of cooking foods in the dry heat of an oven. During baking, moisture within the food is converted to steam, which combines with the dry heat of the oven to cook the food. Common types of foods that are baked include; bread, cakes, jacket potatoes, and pastries.

2.3 Boiling

Boiling is the cooking of foods in a liquid (e.g., water, milk or stock), which is at boiling point. Common types of foods that are boiled include; vegetables, rice and pasta.

Blanching is a very similar cooking technique to boiling and involves immersing food into a boiling liquid for a very short period of time, before being removed and plunged into ice water to stop the cooking process. Common types of food that are blanched include; vegetables and fruits.

2.4 Simmering

Simmering is also a similar cooking method to boiling, except that the food is cooked in a liquid, which is held below boiling point. The simmering point of most liquids is between 85-95°C, and compared to boiling, is a gentler, slower method of cooking. Common types of foods that are simmered include; vegetables, soups and sauces.

Poaching is a comparable cooking technique to simmering, except that the temperature of the liquid the food is cooked in is slightly cooler than simmering point (around 70-85°C). This makes poaching an ideal method of cooking fragile foods such as eggs and fish.

2.5 Grilling

Grilling is the cooking of food using a direct, dry heat. There are several sources of dry heat that may be used for grilling including; charcoal, wood, gas or electric heated grills. Common types of food that are grilled include; fish, meat, vegetables and bread.

2.6 Steaming

Steaming is the cooking of foods by steam. Steam is generated by boiling water, which evaporates and carries the heat to the food. Typical foods that are cooked by steaming include vegetables and fish.

2.7 Roasting

Roasting is the cooking of food using dry heat. This may include cooking in an oven, or over an open flame. Normally, the food is placed in a roasting pan, or rotated on a spit to ensure an even application of heat. Typical foods that are cooked by roasting include meat and vegetables.

Part 2: What happens to food when it is cooked?

Heating causes a complex series of physical and chemical changes to occur. These changes vary depending on the type of food being cooked and the method used to cook it. The changes may be advantageous e.g., improving the flavour, texture and colour of the food, or they may be disadvantageous e.g., reducing the nutrient value of the food, or the generation of undesirable compounds. The main physical and chemical changes that occur during the cooking of foods are discussed below.

1. Flavour

Caramelisation

Caramelisation produces the desirable flavours and colours (see ‘colour’ section), that are characteristic of many food products such as dark beer, coffee, confectionery and peanuts. The caramelisation reaction occurs when foods containing a high concentration of carbohydrates are cooked at high temperatures using a dry-heat e.g., roasting peanuts, setting-off a chain of chemical reactions:

1. As the food is heated, the sucrose in the food melts and starts to boil. The temperature at which this occurs is known as the caramelisation temperature, which (depending on the types of carbohydrates present in the food), is generally between 110^{o}C – 180^{o}C.

2. Once the caramelisation temperature has been reached, the sucrose begins to decompose into its component monomer molecules, glucose and fructose.

3. A further series of complex chemical reactions take place between the molecules, which, ultimately results in the generation of flavour compounds.

In actual fact, caramelisation generates hundreds of flavour compounds. One of the most important flavour compounds produced is diacetyl. Diacetyl is generated during the initial stages of caramelisation and has a butterscotch flavour, which provides one of the characteristic flavours of caramelised foods. Other important flavour compounds produced during the caramelisation reaction include the furans hydroxymethylfurfural and hydroxyacetylfuran, and maltol from disaccharides and hydroxymaltol from monosaccharides, which together contribute to give the sweet, slightly burnt flavour of the caramelisation reaction.

The flavours generated during caramelisation can vary substantially, depending on the type of carbohydrate undergoing the reaction. However, in general, there is a decrease in sweetness and an increase in burnt, bitter notes in all caramelisation reactions as the temperature is increased. Table 3 describes the variation in flavour during the caramelisation of sucrose.

Table 3: Flavour variation during caramelisation

Caramel description	Temperature (^{o}C)	Caramel Flavour	Caramel colour
Light caramel	180	Intense, very sweet flavour	Pale amber to golden brown
Medium caramel	180-188	Intense sweet flavour	Golden brown to chestnut brown
Dark caramel	188-204	Bitter, non-sweet flavour	Very dark brown
Black	210	Burnt, bitter flavour	Very dark brown / black

Food types that may undergo caramelisation

Any foods that contain high concentrations of carbohydrates e.g., beer, coffee, peanuts and confectionery. The cooking methods that may result in caramelisation are roasting, grilling, baking, frying.

Maillard reaction

The Maillard Reaction is one of the most complex chemical reactions that occurs in the food we eat and is responsible for generating many of the flavour and colour (see 'colour' section) characteristics that we associate with a wide range of cooked foods e.g., toast, meat, coffee and baked goods.

The Maillard Reaction is essentially a chemical reaction between an amino acid and a sugar such as glucose, fructose or lactose. Usually, heat is required to start the reaction that causes a cascade of chemical changes, which, ultimately, result in the formation of a range of flavour and colour compounds.

Similar to caramelisation, hundreds of different flavour compounds are generated during the Maillard Reaction, the types of which are highly dependant on the food being cooked. For example, the Maillard Reaction is responsible for producing many sulphur containing compounds, which contribute to the savoury, meaty, flavour characteristics of cooked meat.

Food types that may undergo the Maillard Reaction

Any foods that contain both protein and carbohydrate e.g., meat, biscuits, bread, coffee and nuts. The cooking methods that may result in the Maillard eaction are frying, baking, grilling and roasting.

Starch degradation

The polysaccharide starch is present in all plant seeds and tubers, which means it can be found in many foods such as pasta, rice, bread, potatoes and oats. It is a common form of carbohydrate, composed of several thousand glucose units, linked together by glycosidic bonds. When foods containing starch are cooked, the heat can break the glycosidic bonds linking the glucose units together and effectively break-up the polysaccharides to release the glucose monosaccharides. This imparts a natural sweetness to the cooked food.

Food types that may undergo starch degradation

Any foods that contain starch e.g., rice, pasta, bread, potatoes, wheat and oats. The cooking methods that may result in starch degradation are boiling, baking, roasting, frying, grilling and steaming.

2. Colour

Caramelisation

As well as the generation of important flavour compounds, the caramelisation reaction is one of the most important types of browning processes in foods. During the caramelisation reaction, molecules known as caramels are generated. Caramels can be divided into three groups; Caramelans, Caramelens and Caramelins, and it is these compounds that are responsible for the characteristic brown colour of caramelised foods. As with flavour generation during the caramelisation reaction, the colour of caramel also varies depending on the type of carbohydrate undergoing the reaction. However, for all caramelisation reactions, the colour becomes darker as the temperature is increased. Table 2 describes the changes in colour during the caramelisation of sucrose.

Food types that may undergo caramelisation

Any foods that contain high concentrations of carbohydrates e.g., beer, coffee, peanuts and confectionery.

Cooking methods that may result in caramelisation

Roasting, grilling, baking and frying

Maillard reaction

Along with caramelisation, the Maillard Reaction is another of the most important browning processes in foods. The complex pathways of chemical reactions, not only generate important flavour compounds, but they also produce brown colour compounds known as melanoidins. Melanoidins give many foods their characteristic colouring e.g., coffee, bread and meat.

Food types that may undergo the Maillard Reaction

Any foods that contain both protein and carbohydrate e.g., meat, biscuits, bread, coffee and nuts.

Cooking methods that may result in the Maillard Reaction

Frying, baking, grilling and roasting

Loss of pigmentation

The main foods containing pigments and therefore likely to be prone to losing pigmentation during cooking, are fruits and vegetables. There are three families of pigments found in fruit and vegetable plants, which vary depending on the ripening stage of the plant and the cooking method: chlorophyll – green pigment, carotenoids –pigments ranging from yellow to deep red, and the flavonoids; anthocyanins – red, blue or purple pigments according to the pH, and anthoxanthin – white pigment.

The pigment chlorophyll is responsible for photosynthesis and can be found in many fruits and vegetables such as cabbage, broccoli, kiwi fruit and green apples. Chlorophyll is a fat-soluble pigment and thus, may leach from fruit and vegetables if they are cooked in a medium containing fat e.g., stir-frying. As well as the cooking medium, the chlorophyll pigment may be affected by the length of cooking. Initially, as foods containing chlorophyll are heated, the pigment becomes deficient of air. This results in the appearance of a bright green colour. However, as cooking continues, acids in the cells of the fruit or vegetable are released and cause a chain reaction resulting in the conversion of chlorophyll to pheophytin a (a grey-green coloured pigment), or pheophytin b (an olive-green coloured pigment). Over time, the chlorophyll continues to degrade to an eventual yellowish colour.

Long cooking methods, with a fatty cooking medium, will therefore have a detrimental effect on the concentration and intensity of the chlorophyll pigment that remains in fruit and vegetables during cooking.

The carotenoid pigments are found in fruits such as lemons, oranges, strawberries, and vegetables such as peppers, carrots and sweet potatoes. Similar to chlorophyll, carotenoids are also fat-soluble colorants, which means cooking methods involving the use of fats may also cause leaching of the pigment. As well as leaching, carotenoids can undergo oxidation, which occurs when the carotenoid cells come into direct contact with the air and react with oxygen molecules. This reaction leads to the degradation of the pigment. Cooking methods, which expose fruits and vegetables containing carotenoids to the atmosphere for long periods of time e.g., boiling without a lid, will therefore cause the depletion of the pigment, resulting in paler coloured food.

Anthocyanins are found in fruits such as blueberries, cherries and red plums, and vegetables such as red potatoes and aubergines, whilst anthoxanthins are found in fruits such as apples, and vegetables such as cauliflower, onions and potatoes. Both anthocyanins and anthoxanthins are water-soluble pigments and thus may leach into cooking water during soaking or prolonged heating. Cooking methods avoiding water such as stir-frying will thus minimise the loss of these flavonoids during heating.

Food types that may undergo pigment loss

Fruit and vegetables. The cooking methods that may result in pigment loss are boiling, frying, grilling, steaming and roasting.

3. Texture

Protein denaturation

Many foods contain proteins, such as meat, fish, eggs, vegetables, nuts and pulses. Proteins are large molecules, composed of strands of amino acids, which are linked together in specific sequences by the formation of peptide bonds. Proteins form different 3-dimensional structures, by the folding and subsequent bonding of the amino acid strands. Generally, the bonds which link the folded amino acid strands together (mostly hydrogen bonds), are much weaker than the strong peptide bonds forming the strands.

During cooking, the heat causes the proteins to vibrate violently, which results in the breakage of the weak hydrogen bonds holding the amino acid strands in place. Ultimately, the protein unravels to re-take its initial form of amino acid strands.

The denaturation of protein molecules in foods usually causes a substantial change to the texture of the product. For example, egg white is composed of two key proteins; ovotransferrin and ovalbumin. As the egg white is heated, ovotransferrin begins to denature first, entangling and forming new bonds with the ovalbumin. As the temperature increases, ovalbumin then starts to denature, unravelling and forming new bonds with the ovotransferrin, until denaturation and rearrangement of the protein molecules are complete. In this case, the rearrangement of the protein molecules results in the change of a runny, fluid texture to a rigid, firm texture.

Conversely, protein denaturisation can also cause the formation of softer textures. For example, the protein collagen, which is the major component of the connective tissue in meat, has a tough, chewy texture. However, during cooking, the weak hydrogen bonds are broken and the protein begins to decompose and react with water molecules to form gelatine. This tenderises the meat, giving it a softer, more palatable texture.

Food types that may undergo protein denaturation

Any foods containing protein e.g., meat, fish, eggs, pulses. The cooking methods that may result in protein denaturation are boiling, frying, grilling, roasting, steaming and baking

Polysaccharide gelatinisation

Foods containing the polysaccharide starch, such as corn flour and rice flour, are often used to create and / or thicken sauces. This is because the cooking of these foods causes a process known as starch gelatinisation.

The starch granule is made up of two polysaccharide components, known as amylose and amylopectin. Amylose has a linear chain of glucose units, whilst amylopectin has a branched structure of glucose units. When cooked in water, the starch granules absorb water and swell. At the same time, amylose leaches out of the granules and bonds to form organised lattice structures, which trap the water molecules causing the thickening of the mixture.

Food types that may undergo starch gelatinisation

Any foods containing starch e.g., potatoes, wheat, rice, pasta. The cooking methods that may result in starch gelatinisation is boiling.

Polysaccharide degradation

Many plant foods, in particular vegetables, maintain their rigidity by the incorporation of polysaccharides such as cellulose and pectin in the plant walls. As with the degradation of starch, cellulose and pectin can also be broken down into their monosaccharide constituents during cooking, resulting in the substantial softening of foods containing these polysaccharides.

Foods containing polysaccharides such as cellulose and pectin e.g., vegetables. The cooking methods that may result in polysaccharide degradation are boiling, frying, grilling, roasting and baking.

4. Nutritional Composition

Vitamins

Vitamins are essential nutrients, without which the body cannot function properly. There are two main types of vitamins; water-soluble and fat-soluble (Table 4).

Table 4: List of water-soluble and fat-soluble vitamins

Water-Soluble		Fat-Soluble	
Vitamin	Scientific Name	Vitamin	Scientific Name
B1	Thiamine	A	Retinol
B2	Riboflavin	D	-
B3	Niacin	E	Tocopherol
B5	Pantothenic acid	K	-

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B6	Pyridoxine		
B7	Biotin		
B12	Cobalamin		
C	Ascorbic acid		

As the name suggests, water-soluble vitamins are highly soluble in water and tend to be found in foods that have high water contents such as fruits and vegetables. Similarly, fat-soluble vitamins are highly soluble in fat and tend to be found in foods that have high fat contents such as dairy products, vegetable oils and oily fish.

The differences in vitamin solubility mean that the method by which foods are cooked has a substantial influence on the final vitamin content. Due to their tendency to disperse in water, water-soluble vitamins in particular are heavily affected by cooking processes that involve immersing food in water for long periods of time e.g., boiling. In contrast, fat-soluble vitamins tend to be lost during cooking processes where foods are cooked in fat e.g., frying, or when fat is lost from the product e.g., grilling.

As well as the cooking medium, the length of heating can also affect the vitamin content of foods. Both fat-soluble and water-soluble vitamins are susceptible to heat, with the latter being particularly sensitive. Short cooking methods such as stir-frying and blanching help to reduce the heat degradation of vitamins, compared to longer cooking methods such as roasting.

Food types that may result in the loss of vitamins

Any foods containing vitamins e.g., fruit and vegetables. The cooking methods that may result in the loss of vitamins are frying, boiling, grilling, steaming and roasting.

Minerals

As with vitamins, minerals are also essential nutrients, without which the body cannot function correctly. There are two types of minerals, known as essential minerals and trace elements. Essential minerals or macrominerals are those minerals needed by the body in relatively large amounts (>100mg per day), whilst trace elements or microminerals are those minerals needed by the body in relatively small amounts (<100mg per day). Heating itself does not affect mineral levels but are usually leached if cooked in boiling water. Minerals tend to have a higher heat stability and are less affected by cooking methods which involve heating foods for longer periods of time.

Food types that may result in the loss of minerals

Any foods containing minerals e.g., meat and vegetables. The cooking method that may result in the loss of minerals is boiling.

5. Generation of Undesirable and Desirable Compounds

5.1 Undesirable compounds

Over recent years, it has become evident that cooking foods can lead to the generation of undesirable compounds. The generation of potential carcinogenic compounds has received particular attention due to the serious nature of their possible consequences.
Perhaps the most well known of these compounds are nitrosamines. Sodium nitrite is used for the curing of meat and the associated smoked taste, the prevention of bacterial growth and a desirable dark red colour. During cooking, nitrosamines are produced from nitrites and secondary amines. They are found in some smoked, grilled or fried foods, such as charred meat, and they can also be found in tobacco.

Several other compounds are considered as carcinogenic, such as acrylamide and heterocyclic amines, which are both formed as a result of the Maillard Reaction, as well as furan, polycyclic aromatic hydrocarbons, and chloropropanols/esters. Furan, formed by several pathways, is a volatile chemical that tends to evaporate quickly. However, when it cannot escape for some reason (e.g. in sealed cans or jars), it remains present in the food for some time. Polycyclic Aromatic Hydrocarbons (PAHs) are produced when any incomplete combustion occurs, from grilling roasting and frying, but also smoking and drying (dependant on fat content). Most PAHs are not carcinogenic, although a few are (such as pyrene and benzo(a)pyrene). Chloropropanols/esters have also been linked with the thermal treatment of processed food products.

Nevertheless, most food processing contaminants can be reduced by modifying cooking times/temperatures or by the inclusion of certain additives, while not cooking food can lead to higher health risks, due to microbial contamination for example.

Food types that may generate undesirable compounds when cooked

Foods containing starch and protein e.g., meats, biscuits, bread, potatoes. The cooking methods that may result in the generation of undesirable compounds are frying, baking, grilling, smoking and roasting.

5.2 Desirable compounds

Despite the fact that cooking can cause the generation of undesirable compounds, research has shown that cooking can also increase the formation of favourable molecules and the bio-availability of some antioxidants, such as lycopene. Unlike heterocyclic amines and acrylamide, antioxidants are known to be beneficial to human health. Antioxidants are molecules that can slow down or prevent other molecules from undergoing reactions that can cause damage to human cells. Antioxidants are also generated during the Maillard Reaction.

Food types that may generate desirable compounds when cooked

Mostly starchy foods e.g., meats, biscuits, bread, potatoes. The cooking methods that may result in the generation of desirable compounds are frying, baking, grilling and roasting.

Cooking therefore has a substantial impact on the final sensory (organoleptic), nutritious and health properties of many different foods. Table 5 provides a summary of the main cooking methods and the effect they can have on the final characteristics of cooked food.

TABLE 5: Summary table of the effects of different cooking methods on the properties of cooked foods

Cooking method	Food types	Chemical processes	Cooking e
Frying	Meat, fish, eggs, vegetables	Maillard reaction, caramelisation, polysaccharide degradation, loss of pigmentation, protein denaturation, vitamin loss, undesirable & desirable compound generation	Colour, flavour, te nutritional compo undesirable & des compound genera
Baking	Bread, biscuits, pastry, cakes	Caramelisation, maillard reaction, polysaccharide degradation, protein denaturation, undesirable & desirable compound generation	Colour, flavour, te undesirable & des compound genera
Boiling	Rice, pasta, vegetables, pulses	Polysaccharide degradation, loss of pigmentation, protein denaturation, polysaccharide gelatinisation, vitamin loss, mineral loss	Colour, flavour, te nutritional compo
Grilling	Meats, fish, vegetables, fruits, bread	Caramelisation, maillard reaction, polysaccharide degradation, loss of pigmentation, protein denaturation, vitamin loss, undesirable & desirable compound generation	Colour, flavour, te nutritional compo undesirable & des compound genera
Steaming	Fish, vegetables	Polysaccharide degradation, loss of pigmentation, protein denaturation, vitamin loss	Colour, flavour, te nutritional compo
Roasting	Meat, vegetables, nuts	Caramelisation, maillard reaction, polysaccharide degradation, loss of pigmentation, protein denaturation, vitamin loss, undesirable & desirable compound generation	Colour, flavour, te nutritional compo undesirable & des compound genera

Part 3: Do the same changes occur to food when cooked on a larger scale?

The Food Industry

The food industry in Europe is made up of approximately 310,000 companies and employs over 4 million people. With an annual turnover of more than €800 billion, the food industry is one of Europe's most important and dynamic industrial sectors.

The manufacturing of food products across Europe is diverse, varying from small-scale units, producing handmade products to large-scale, highly automated factories producing tonnes of products per day. However, regardless of the volume of food being manufactured, the process is the same as that in the kitchen at home, but just on a larger scale. Indeed, the industrial processes are controlled, standardised and their impacts are known and monitored in order to maximise and give a consistent final product quality.

How food products are manufactured

Despite the massive diversity in the manufacturing of food products within Europe, the basic process by which a product is created, developed and manufactured is universal across the food industry. To illustrate this, the following provides an overview of how a common food product, in this case a tomato pasta sauce, may be produced from the initial stages of development to large-scale production.

Initial Development

The first stage of developing a new food product, or improving an existing one, is carried out in a kitchen. New recipes are generated and tested using the same equipment and quantities of ingredients that would be used in the kitchen at home. During this stage, recipes may be modified many times until the desired final product is produced, so small-scale techniques are used to reduce food wastage and cooking time.

Tomato pasta sauce

The new tomato pasta sauce recipe is cooked using standard kitchen equipment e.g., kitchen scales, saucepan, knife, chopping board, vegetable peeler, wooden spoon and hob, to produce around 500g of sauce. The quantities of vegetables, seasoning and the cooking time and temperature are modified several times before the desired flavour, texture and colour is obtained.

Pilot Level

Once the initial development stage is complete, the new recipe is produced on a larger scale to test if increasing the scale of manufacturing causes any changes to the final product. This is known as ‘scaling-up’. Scaling-up is usually done using small-scale versions of the equipment used in the factory, known as pilot level equipment. During the scale-up testing, it is likely that variables such as the cooking time / temperature may need to be modified, so, similar to the initial development stage, the recipe may be modified several times during the pilot level trials to ensure the desired final product is still obtained.

Tomato pasta sauce

The tomato pasta sauce recipe is cooked using pilot level equipment e.g., industrial scales (able to weigh up to 10kgs), steam-heated boiling pan with mixing paddle (holding 5kgs sauce), automated vegetable peeler and dicer (capable of preparing 2kg batches of vegetables) to produce around 5kgs of sauce. The cooking time and temperature of the pasta sauce are modified to accommodate the larger volume of food being cooked.

Factory Trial

On completion of the pilot level stage, a factory trial may be carried out prior to actual full-scale production. The recipe is produced on a full-scale using the equipment it will actually be manufactured with. This is a final test to check that no further amendments to the recipe need to be made before large volumes of the product are produced for consumption.

Tomato pasta sauce

One batch of the tomato pasta sauce is produced using full-scale factory equipment e.g., industrial scales (able to weigh up to 20kgs), steam-heated boiling pan with mixing paddle (holding 50kgs sauce), automated vegetable peeler and dicer (capable of preparing 10kg batches of vegetables) to produce around 50kgs of sauce. Only a minimal change to the cooking time is required at this stage.

Full-Scale Production

This is the final step of the manufacturing process, where continuous full-scale batches of the product are produced, using the final recipe from the scale-up or factory trial stage.

Tomato pasta sauce

Continuous batches of the pasta tomato sauce are produced, averaging a production volume of 500kg per day.

Hence, the manufacture of food products starts on a kitchen-level, and progresses up to large-scale production. The same cooking techniques are used during each stage of the manufacturing process, but on an increasingly large scale.

<u>Regardless of the volume of food being produced, food products undergo the same cooking processes to those prepared at home in the kitchen</u>. Consequently, changes to the flavour, colour, texture, nutritional composition and the generation of desirable and undesirable compounds of foods produced in the kitchen are the same as those produced during large-scale food production.

Examples of quantities of ingredients involved in tomato sauce recipe at industry and home scales.

Tomato sauce production	Industry (kg per month)	Home (kg)
Tomato	100,000	2

Sugar	600	2 sp
Vinegar, salt, spices	1,200	3 sp
Colour, preservatives	25	
Production capacity	25,000	1

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