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Can The Reaction That Makes Food Delicious Be Harmful?

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ABSTRACT

Most food ingredients undergo a cooking process before consumption. Cooking raw ingredients offers many benefits; nevertheless, depending on the cooking method, nutrients may be lost or altered, resulting in a decreased nutritional value. Meals are essentially consumed to obtain the nutrients contained in foods. Cooked food supports physical activity and sustains health through the ingested nutrients. Therefore, eating food is not commonly assumed to make us sick or harm our health. However, some cooking methods result in the production of harmful substances, the ingestion of which can deteriorate health. In this article, we present and elaborate on the reactions producing harmful substances during the cooking process. The review article may provide insights into cooking processes that should be avoided to maintain good health.

INTRODUCTION

Food items for human consumption are rarely served raw at the table and involve some type of cooking process. An exceptional case is green salads, which are usually prepared by tearing raw vegetables by hand or chopping them with a knife into bite-size pieces. Staple foods, such as rice and bread, undergo cooking, fermenting, and baking before they can be safely consumed. Many main and side dishes often go through a heating process, such as boiling, baking, stir-frying, and steaming (Table 1). These processes serve many purposes, such as softening the ingredients by heating to make the food easier to eat, changing the appearance and taste to make food appealing, and facilitating the absorption of nutrients[1)]. Depending on the cooking method, nutrients may be lost or altered, resulting in the decreased nutritional value of the ingested food. The process of boiling consists of heating ingredients at ~100°C; however, water-soluble vitamins dissolve in the hot water (or broth) at this temperature, decreasing the nutritional content and altering the quality of food.

The purpose of eating is to absorb the nutrients contained in various ingredients[2)], support physical activity, and sustain health through the ingested nutrients. Nutrients serve as energy sources, form structural elements of the body, and regulate body functions. Nutrients should be consumed in a well-balanced manner to efficiently maintain these functions. Eating food is not commonly assumed to make us sick or harm our health. However, an unbalanced or excessive intake of nutrients may cause diseases. Cooking methods result in the production of harmful substances whose ingestion can be detrimental to health. If food initially contains harmful ingredients, it is advisable to either not consume it or remove the harmful substances by processing it before consumption. For example, in potatoes, green spots and sprouts contain toxic substances, such as solanine; hence, these parts should be removed before cooking. The tiger puffer fish carries a toxic substance called tetrodotoxin. Tetrodotoxin is found in large quantities in the internal organs than in muscles; hence, only flesh can be consumed with preparations such as sashimi, hot pot, or fried. The ovarian part is highly toxic. In some areas, such as the Ishikawa prefecture in the Hokuriku region, a method has been devised to reduce the toxicity of the ovarian part and allow consumption by preserving it in sake cake. The generation of harmful substances by cooking is an unintended event and should be prevented. In this article, we describe the reactions that generate harmful substances during the cooking process.

Caramelization

A typical example of the production of harmful substances by heating is charring. When fish or meat is burnt, proteins are decomposed, and heterocyclic amines are generated. These substances are known carcinogens. Some people confuse caramelization with charring because the color of the food changes to brown; however, caramelization is a completely different process[3]. Charring is the so-called carbonization of organic matter. In addition, caramelization implies creating caramel. The caramelization reaction proceeds easily: heating carbohydrates, such as sugar or glucose, changes their color to brown, creating a sweet and fragrant aroma[4]. The human tongue can sense five taste modalities: sweetness, saltiness, acidity, bitterness, and umami. Nevertheless, people recognize more complex tastes as a result of the combination of smell and taste. The sweet and fragrant aroma component produced by caramelization mixes with other smells, producing an indescribable appetitive odor. People recognize this as a taste.

When caramelization occurs, chemical changes in sugars produce flavoring components with a complex structure. The color of foods that develops during baking (brown or blackening as if burnt) is not entirely due to carbonization; baked foods are tasty because they also contain the products of the Maillard reaction described below. This is a useful reaction in the process of enhancing food taste. A well-known food is caramel sauce used primarily in sweet preparations, such as puddings and cakes.

Maillard reaction

The Maillard reaction also produces a brown color, but its raw materials are sugar and protein[4]. Originally derived from the work of the French scientist Louis Camille Maillard, the reaction is also referred to as the brown reaction[5]. As a result of this reaction, the food turns brown and appears appetizing. In addition, the Maillard reaction produces a fragrant aroma during heating that can stimulate appetite. Umami components may be included among the produced substances because of this reaction, resulting in a delicious flavor. The reaction has an overall positive effect on food flavor and appearance.

The outline of the Maillard reaction is as follows: When meat and fish are heated, protein breakdown progresses, and amino acids are produced. Amino acids react with starch and sugar contained in food or sugar contained in seasoning. Specifically, a reaction (a type of aminocarbonyl reaction) proceeds between an amino group (NH_2) of an amino acid molecule

and a carbonyl group (C=O) of a sugar molecule, producing various substances. As a result, food emits fragrant odors and umami ingredients are enhanced. The Maillard reaction is a well-known reaction, and to date, more than 200 types of chemical substances are known to be generated by heating foodstuffs. However, the mechanism has not been completely elucidated yet.

The Maillard reaction is caused not only by heating food but also by aging/fermentation processes[5]. Typical examples are miso and soy sauce; common manufacturing methods of these foodstuffs do not involve heating. Although directly linked to the deliciousness of the food, the Maillard reaction is also part of several harmful reactions in the body[5]. For example, it has been associated with diabetic complications and aging. Therefore, the Maillard reaction can lead to adverse health effects.

Acrylamide (structural formula: CH_2=CHCONH$_2$) is often cited regarding safety issues. Even during cooking methods, such as baking and frying, trace amounts of acrylamide are produced through the Maillard reaction between the amino acid asparagine (or a protein containing asparagine) and sugar (Table 2). Acrylamide is mainly used in non-food products, such as adhesives and paints. When absorbed in large amounts, acrylamide acts on the central and peripheral nervous system and causes disorders, such as muscle weakness, sensory abnormalities and paralysis, and gait disturbances[6]. In addition, high acrylamide intake increases the risk of cancer. Acrylamide is easily formed during frying, baking, or roasting at temperatures of 120°C or higher. In contrast, acrylamide is generally not formed during boiling, steaming, or poaching[7], which may be because the temperature of hot water and steam is <100°C at atmospheric pressure.

Meataging

Aging refers to the process of modifying the color, taste, aroma, and texture of food by placing it in an appropriate environment to convert it into a favorable state[8]. In some cases, the process borrows the power of microorganisms existing in the environment. Aging is considered a degradation process under controlled conditions to bring out the flavor and improve the taste of meat. It is similar to the processes that turn fruit sweeter and softer or result in color changes. To improve the quality of foodstuffs, it is necessary to create suitable conditions, such as temperature, humidity, and time; if the conditions are inappropriate, the

quality of foodstuffs will deteriorate. Therefore, degradation alone is not sufficient to enhance flavor.

The mechanism underlying flavor enhancement during the aging process involves proteolytic enzymes that break down proteins in meat and fish muscles into amino acids, increasing the amount of umami and sweetness[8]. Glycogen is converted to glucose (sugar) by enzymes such as glucagon. Thus, glucagon contributed considerably to the aroma due to the Maillard reaction (there action between sugars and amino acids) during cooking. As aging progresses, proteolytic enzymes in the meat cleave collagen fibers, unraveling the bundles of myofibrils. During chewing, the texture of the meat becomes soft and moist.

Aged beef is produced via the function of autolytic enzymes that decompose proteins into peptides, which are then converted into amino acids (Table 3). The umami-tasting glutamic acid and aspartic acid content are several times higher in meat aged for a long period under optimum conditions than in fresh meat. In addition to amino acids, umami components include nucleic acid-derived compounds, such as inosinic and guanolic acid; the balance between amino acids and nucleic acid-derived compounds determines the flavor of food. The flavor of the meat enhances if aging is well controlled, whereas it decreases if aging is not controlled. The reasons for uncontrolled aging may be the failure to remove mold, prevent mold growth, or stop the process when sweetness and umami components increase. In addition, such foods may affect consumer health. An appropriate degree of aging may increase the nutritional content of food; however, the same nutrients may be utilized as energy sources by microorganisms, leading to mold growth.

CONCLUSION

As discussed above, harmful substances may be produced in the cooking process. Although it is possible to avoid cooking to some extent, it is often challenging to eliminate the process. Cooking adds layers of flavor; hence, it cannot be completely avoided. If people get concerned and focus only on safety issues, they will not be able to enjoy a meal.

In Japan, an independent organization of the Cabinet Office, the Food Safety Commission of Japan, investigates and educates on food safety from a neutral standpoint and provides opinions on food toxicity. In their opinion: “According to this content, it is considered that all substances can be toxic. Since each has an amount and concentration that are harmful to people, it is necessary to take it so as not to exceed that value. Salt and sugar, which are

considered essential, can be harmful if taken too much[9].” Therefore, it is necessary to consider the amount of intake for each substance and judge the risk[5]. If people pursue zero risk, they will not be able to cook at all.

Heating offers a wealth of advantages as eliminates the microorganisms that adhere to or are contained in raw foods and can cause food poisoning. If food is not heated, it will be challenging to kill harmful bacteria. It should be well understood that heating food has both advantages and disadvantages. In essence, the Food Safety Commission of Japan recommends an unbiased and balanced intake of ingredients[5]. In addition, it is recommended to avoid burning and over-coloring food during cooking to prevent eating poor-quality food and allow consumers to review their eating habits.

On heating ingredients at 160–180 °C, such as when baking, stir-frying, and frying, a crispy texture, aroma, and color get incorporated into the flavorful food. Cooking processes should not lead to physical discomfort, and one should not overstress over the consequences of these processes. A small amount of toxic substance generated while cooking can be disregarded if the cooked food tastes good or its commercial value increases. Excessive stress and overpotential harms from cooking should be avoided. The simplest way to minimize the harmful effects of cooking is to avoid eating the same food continuously. It is safe to consume various ingredients in a well-balanced manner to reduce the potential harmful risk of one substance while enjoying different food items. Understanding and adopting these practices is of utmost importance for consumers.

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Table 1 Basic cooking methods

Cooking method	Details
Baking	The simplest cooking method that involves heating foodat high temperatures. It is suitable for cooking meat and fish and can enhance the flavor of ingredients.
Stir-frying	A cooking method that involves heatingfood quickly over a high heat source. Since food is cooked at a high temperature for a short time, there is little loss of nutritional value. Since the frying time is less, some ingredients may be boiled or oil-passed in advance.
Boiling	Immersion in boiling water. A cooking method that is used as is or as a preparation step.
Poaching	A cooking method in which ingredients are heated in a seasoning liquid to~100°C. Unlike boiling, the purpose is not only to cook but also to soak in the flavorful medium.
Deep-frying	A cooking method that involves heating oil at high temperatures. In the case of deep-frying, oil is heated to ~200 °C; hence, it is possible to shorten the heating time while thoroughly cooking the inside of food. Frying is expected to contain umami and add flavor.
Dressing	A cooking method in which seasonings are mixed with prepared ingredients. Vegetables are the main ingredients; hence,this is considered a healthy cooking method.
Steaming	A cooking method in which water is heated to produce steam, and the heat of the steam is used to heat the ingredients. Since food is not heated in water, the taste and nutritional components of the ingredients are preserved.

Based on the data in reference 1).

Table 2 Sources of acrylamide in Japan

Food type	Food example	Intake ratio (%)*	Specific acrylamide content (average mg/kg – maximum value mg/kg)
Vegetables cooked at a high temperature	French fries Stir-fried bean sprouts, onions, cabbage	56.0	0.27–1.10
Beverages	Coffee Green Tea Oolong Tea Barley tea	17.0	
Snacks	Potato chips Cookie Rice crackers Dorayaki (two small pancakes with bean jam in between)	16.0	0.57–2.10 0.17–0.56 0.11–0.37 0.11–0.32
Cereals	Bread	5.3	
Others	Curry roux	6.2	

*The intake ratio indicates the ratio of Japanese people consuming acrylamide in the food.

Based on the data in reference 7).

Table 3 Changes in amino acid content during beef aging

Amino acid type	Amino acid content		Taste
	Before aging (ppm)	30 days after aging (ppm)	
Alanine	9859	14205	Sweetness
Arginine	10529	15948	Bitter taste
Aspartic acid	16006	22094	Umami/acidity
Cysteine	1219	2034	Bitter taste
Glutamic acid	27927	39160	Umami/acidity
Glycine	8059	9738	Sweetness
Histidine	7561	9736	Bitter taste
Isoleucine	8737	12821	Bitter taste
Leucine	13708	19248	Bitter taste
Lysine	15921	22905	Bitter taste
Methionine	5160	6292	Bitter taste
Phenylalanine	7167	9727	Bitter taste
Proline	7341	8668	Sweetness
Serine	6288	8300	Sweetness
Threonine	4894	8940	Sweetness
Tyrosine	5797	7504	Bitter taste
Tryptophan	1800	2593	Bitter taste
Valine	8058	11642	Bitter taste

Based on the data in reference 8).