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Review

Mitigation strategies of acrylamide, furans, heterocyclic amines and browning during the Maillard reaction in foods

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ABSTRACT

The Maillard reaction (MR) occurs widely during food manufacture and storage, through controlled or uncontrolled pathways. Its consequences are ambiguous depending on the nature and processing of the food products. The MR is often used by food manufacturer to develop appealing aromas, colour or texture in food products (cereal based food, coffee, meat…). However, despite some positive aspects, the MR could decrease the nutritional value of food, generate potentially harmful compounds (e.g. acrylamide, furans, heterocyclic amines) or modify aroma or colour although it is not desired (milk, fruit juice). This paper presents a review of the different solutions available to control or moderate the MR in various food products from preventive to removal methods. A brief reminder of the role and influence of the MR on food quality and safety is also provided.

Contents

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1. Introduction

Since its discovery in 1912 by Louis Camille Maillard, the Maillard reaction (MR), also called the non-enzymatic browning reaction, has been widely studied because it occurs in food and in living beings (Gerrard, 2006). In food, the Maillard reaction commonly occurs during cooking, preservation and processing, leading to the formation of the so-called Maillard reaction products (MRPs) (Kwak & Lim, 2004).

The MR is often used by food manufacturers to develop an appealing colour, a crusty texture and appetising aromas to increase food palatability. The MR notably improves the organoleptic qualities of baked food (bread, cakes, potato-based products, meat, fish), cocoa and coffee (Markowicz, Monaro, Siguemoto, & Séfora, 2012). Different types of cooking methods are used (baking, roasting, frying…) leading to the formation of various aromas and modifications of texture and colour greatly appreciated by consumers. However, the MR may sometimes occur when it is not desired (e.g. during pasteurisation) leading to modification of colour or aroma. In general, the MR is not desired in milk, some dairy products or in fruit juices as a brown colour could appear, which is not desired by consumers in those types of products.

Apart from sensory modifications, the MR impacts the nutritional and toxicological properties of food. Some of the MRPs formed during the MR, particularly melanoidins, have been reported to present beneficial properties for health such as antioxidant, anti-inflammatory or anti-aging factor (Delgado-Andrade, 2014). Coffee and bread crust melanoidins have mostly been studied, coffee melanoidins showing particularly beneficial effect on health (Delgado-Andrade, 2014; Morales, Somoza, & Fogliano, 2012). Beside these positive health effects, the MR also produces some MRPs having negative health effects. Acrylamide, furan, HMF and heterocyclic amines are particularly studied as they have been identified as potential harmful compounds. Acrylamide, furan and HMF are mainly formed in cereal and potato-based products whereas heterocyclic amines are present in meat and fish products. Strategies to limit the formation of potential harmful compounds in food constitute a wide field of research. The research to limit the formation of some MRPs in food thus overlaps with medical studies as the MR also occurs directly in the human body (known as glycation) leading to chronic diseases (such as diabetes and osteoporosis) and aging (Gerrard, 2006). The comparison of the strategies developed to mitigate the MR in food or in vivo is interesting as some solutions are efficient in both cases (e.g. polyphenols).

Regarding the positive and negative effects of the MR on the sensory and nutritional quality of food, the main challenge for the food industry is now to find the best compromise to produce appealing and healthy foods.

This review focuses on the different strategies to control the MR in food products. After a brief reminder of the parameters influencing it, we explain why it is sometimes necessary to limit its occurrence in food. The core of the article presents the strategies to mitigate the MR in food, whether to protect some characteristic of the product or to prevent the formation of toxic compounds (acrylamide, furans, HAs). Various types of food products are considered, such as vegetables, meat, cereals, and dairy products, which have different problems (acrylamide, heterocyclic amines, colour, odour) but for which the same solutions are sometimes effective. Such a review could be an opportunity for food manufacturers to discover novel solutions. For the purpose of clarity, the solutions to mitigate the MR are presented according to the nature of the food product (Table 1, 90 references) and through the processing applied (Fig. 1). This review will thus provide various key information for food manufacturers to control the MR throughout the process whatever the nature of the food.

2. The Maillard reaction

2.1. Mechanism

The mechanistic pathways of the MR have been widely described in the literature. For more detailed information, the reader is invited to refer to the specific reviews on this topic (Friedman, 1996; Hodge, 1953; Nursten, 2005). The Maillard reaction is a succession of non-enzymatic reactions whose mechanisms are still not completely elucidated (Purlis, 2010). The MR is divided into 3 main steps. The first step, called the initial stage, begins with a sugar-amine condensation followed by the Amadori rearrangement. The resulting products of this first step are colourless, without absorption in ultraviolet light (about 280 nm) (Hodge, 1953; Nursten, 2005).

The second step, called the intermediate stage, includes sugar dehydration and fragmentation and amino acid degradation (Strecker degradation). The Amadori products are degraded into different compounds depending on the pH of the system (Purlis, 2010). Higher pH favours 2,3-enolisation leading to the formation of reductones (e.g. furanone) whereas low pH favours the 1,2-enolisation pathway resulting in the formation of compounds like furfural or HMF (5-hydroxymethylfurfural) (Lertittikul, Benjakul, & Tanaka, 2007; Nursten, 2005). Sugar dehydration thus leads to the formation of furfurals or reductones by the loss of 3 or 2 molecules of water, respectively (Nursten, 2005). Sugar fragmentation occurs through the mechanism of retroaldolisation. The fission products obtained can be volatiles (2,3-butanedione, 2,3-pentanedione) or precursors of volatiles, which contribute to the flavour of food. The dehydroreductones obtained from sugar dehydration and the fission products obtained from sugar fragmentation lead to the formation of aldehydes through the Strecker degradation. This involves the oxidative deamination and decarboxylation of an α-amino acid in the presence of a dicarbonyl compound (Whitfield, 1992). The products obtained are aldehydes containing one less carbon atom than the original amino acid (Whitfield, 1992). They often play an important role in the aroma of foodstuffs (Whitfield, 1992; Zehentbauer & Grosch, 1998; Van Boekel, 2006). The products of the intermediate stage are colourless or yellow, with strong absorption in ultraviolet light (Nursten, 2005).

The third step, namely the final stage, comprises aldol condensation, aldehyde-amine condensation and the formation of heterocyclic nitrogen compounds (Hodge, 1953; Nursten, 2005). The highly reactive compounds formed in step 2 undergo polymerisation reactions to form coloured products with high molecular mass called the melanoidins. These pigments are responsible for the colour development observed on foodstuff during thermal processes (e.g. bread, biscuit, meat). The polymerisation reactions also contribute to the hardening of cooked and stored food (Machiels & Istasse, 2002).

2.2. Factors affecting the MR

The factors affecting the MR depend on the type of product and process applied. Obviously, temperature and time are the primary factors