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Review

The use of asparaginase to reduce acrylamide levels in cooked food

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ABSTRACT

Strategies proposed for reducing the formation of the suspected carcinogen acrylamide in cooked foods often rely on a reduction in the extent of the Maillard reaction, in which acrylamide is formed from the reaction between asparagine and reducing sugars. However, the Maillard reaction also provides desirable sensory attributes of cooked foods. Mitigation procedures that modify the Maillard reaction may negatively affect flavour and colour. The use of asparaginase to convert asparagine to aspartic acid may provide a means to reduce acrylamide formation, while maintaining sensory quality. This review collates research on the use of enzymes, asparaginase in particular, to mitigate acrylamide formation. Asparaginase is a powerful tool for the food industry and it is likely that its use will increase. However, the potential adverse effects of asparaginase treatment on sensory properties of cooked foods and the need to achieve sufficient enzyme–substrate contact remain areas for future research.

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1. Introduction

It is now over ten years since the Swedish Food Authority and the University of Stockholm confirmed the existence of the suspected carcinogen acrylamide in a variety of heated foods (Tareke, Rydberg, Karlsson, Eriksson, & Tornqvist, 2002). Several months after the announcement, researchers showed that acrylamide is formed from asparagine and reducing sugars during the Maillard reaction (Mottram, Wedzicha, & Dodson, 2002; Stadler et al., 2002). As shown in Fig. 1, asparagine and reducing sugars take part in a conjugation reaction resulting in the formation of *N*-glycosylasparagine, which as a result of high temperature treatment will form a decarboxylated Schiff base. The decarboxylated Schiff base may decompose directly to form acrylamide or may hydrolyse to form 3-aminopropionamide (Hedegaard, Frandsen, & Skibsted, 2008). 3-Aminopropionamide is also believed to be an important precursor of acrylamide (Granvogl & Schieberle, 2006).

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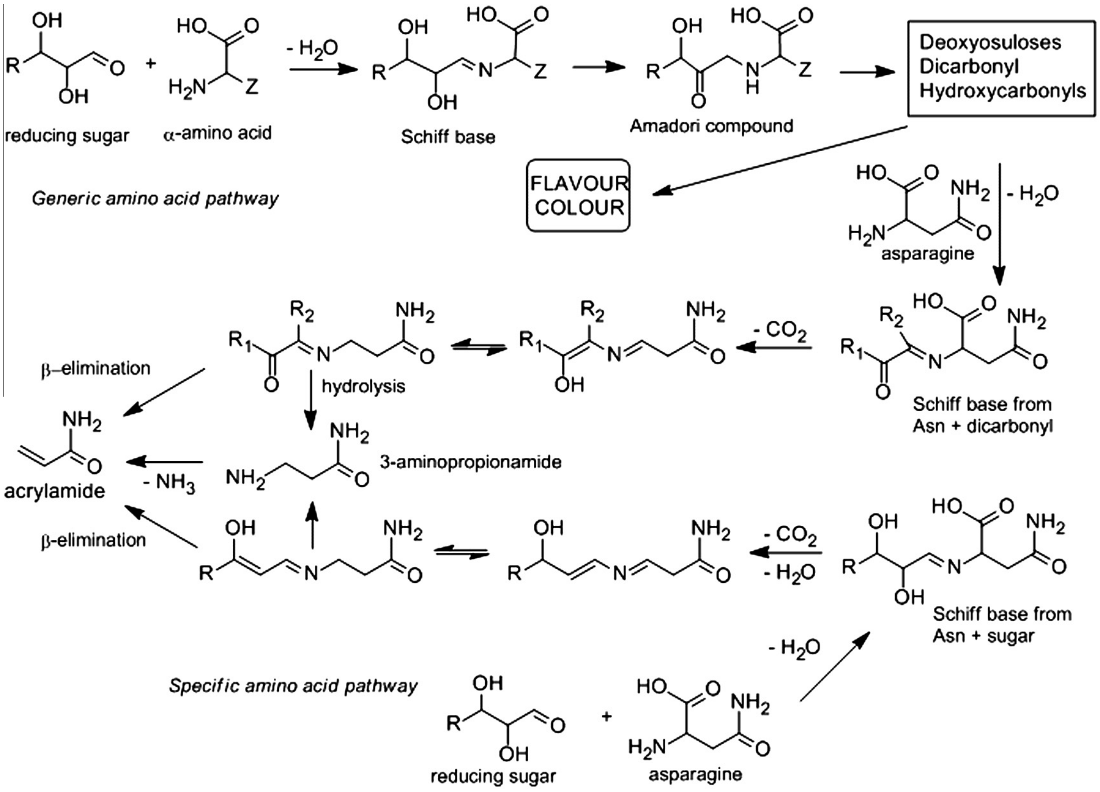

Fig. 1. Mechanism of acrylamide formation. adapted from Parker et al. (2012).

Since 2002, the food industry worldwide has collaborated with scientists, in order to reduce the levels of acrylamide in cooked foods. Mitigation techniques can be separated into three different types. Firstly, starting materials low in acrylamide precursors can be used to reduce the acrylamide in the final product. Secondly, process conditions may be modified, in order to decrease the amount of acrylamide formation. Thirdly, post-process intervention could be used to reduce acrylamide (Pedreschi, Mariotti, & Granby, 2014). While the third approach is not widely considered, an example is the use of supercritical CO_2 extraction to reduce acrylamide levels in coffee. Almost 80% of the acrylamide was removed using this technique (Banchero, Pellegrino, & Manna, 2013), although further sensory tests are needed to validate the effect on food quality.

This review will describe the main mitigation strategies used for acrylamide but will focus on the use of enzymes, in particular asparaginase, to reduce levels of acrylamide precursors. A more general review on acrylamide mitigation has been recently published (Friedman, 2015), while another recent review has covered the latest studies on the sources, purification, and characterisation of L-asparaginase and its application in both the pharmaceutical and food industries (Zuo, Zhang, Jiang, & Mu, 2015a).

2. Acrylamide mitigation strategies

2.1. Raw materials

Decreasing the amounts of acrylamide precursors will have a huge impact on final acrylamide production (Zyzak et al., 2003). However, the effect will be dependent on the relative levels of precursors. If total reducing sugars are present at higher levels than asparagine in a food, reduction in asparagine will have the greater effect on acrylamide formation, and *vice versa*. Numerous papers have demonstrated that acrylamide formation is proportional to reducing sugar concentrations in potato (Elmore et al., 2015; Ohara-Takada et al., 2005; Vinci et al., 2012), while in cereals, such as rye and wheat, acrylamide formation is proportional to asparagine content (Curtis et al., 2010; Halford, Curtis, et al., 2012). Hence potato varieties low in reducing sugars and cereal varieties low in asparagine are sought. Storage may increase levels of reducing sugars in stored potatoes, particularly under low-temperature conditions (Rak, Navarro, & Palta, 2013), while levels of fertilisation, for example nitrogen and sulfur, may have effects on reducing sugars and asparagine levels in both potatoes and cereals (Elmore et al., 2007; Muttucumaru, Powers, Elmore, Mottram, & Halford, 2013; Muttucumaru et al., 2006). It is clear, however, that little or no acrylamide will form in the absence of asparagine, while other components of the food matrix, such as lipid-derived aldehydes (Zamora & Hidalgo, 2008), amino acids such as serine and threonine (Shu, 1999), and other carbonyl-containing molecules (Hamzalioğlu & Gökmen, 2012; Zamora, Delgado, & Hidalgo, 2011), can react with asparagine to form acrylamide.

2.2. Process-based mitigation

Initial mitigation methods involved the control of processing conditions; for instance, lowering pH, reducing cooking temperature and shortening the processing time (Palazoĝlu & Gökmen, 2008). Although these methods achieved an effective reduction of acrylamide, sensory properties of the food were compromised. As the Maillard reaction begins when food is heated, the first option in this type of mitigation method is to lower the temperature and time of heating. However, as the Maillard reaction is also responsible for generating desirable taste and smell in cooked food, sensory properties become unacceptable when cooking temperature is substantially reduced (Masi, Dinnella, Barnaba, Navarini, & Monteleone, 2013).