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Review

Relationship between antioxidants and acrylamide formation: A review

Cheng Jin, Xiaoqin Wu, Ying Zhang *

Department of Food Science and Nutrition, College of Biosystem Engineering and Food Science, Zhejiang University, Hangzhou 310058, PR China

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ABSTRACT

The detection of high level of the neurotoxic and carcinogenic acrylamide in heat-treated foodstuffs in 2002 led to an intensive research effort. Among the parameters affecting the level of acrylamide in foods, the effect of antioxidants had not yet been elucidated satisfactorily. Several researchers have investigated the effect of various antioxidants and antioxidative extracts on acrylamide formation, but the data were discordant. Some studies claimed mitigation while others no effect or even an increase. It can be attributed to the ability of antioxidants with different structures or functional groups to react with acrylamide precursors, with intermediates of the reaction or with acrylamide itself, leading to either reducing or promoting effects. The fact that the same kind of antioxidant, or extract and its representative components behaves differently in different studies might be due to the different reaction conditions among the studies, concentrations of the antioxidant, as well as preparative methods of the extract. This review tried to give a broad overview and evident-based understanding about the role of antioxidants on acrylamide formation.

Contents

1. Introduction

Acrylamide, a colorless and odorless crystalline solid with a melting point of 84.5 °C, is a neurotoxic, genotoxic and probable carcinogenic substance (IARC, 1994) derived through the Maillard reaction in many starch-rich foods, particularly potato crisps, potato chips, crisp bread, bakery products, breakfast cereal and coffee (Friedman, 2003). It has led to intensive research efforts since it was first detected in heat-treated foodstuffs at the level of mg/kg in 2002 by Swedish scientists (Tareke, Rydberg, Karlsson, Eriksson, & Tornqvist, 2002).

* Corresponding author. Tel./fax: +86 571 88982164.
E-mail address: yzhang@zju.edu.cn (Y. Zhang).

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Former studies focused mainly on: (i) accurate analytical methods of acrylamide and its substrates (Biedermann, Biedermann-Brem, et al., 2002; Rosén & Hellenäs, 2002; Zhang, Ren, Jiao, Li, & Zhang, 2011), (ii) formation mechanisms of acrylamide (Mottram, Wedzicha, & Dodson, 2002; Stadler et al., 2002, 2004; Zyzak et al., 2003), and (iii) the possible mitigation strategies in heat-processed foods. Existing strategies to reduce acrylamide content include three basic aspects: modification of raw materials, optimization of processing conditions and addition of exogenous additives. For raw materials, the key is to control the content of carbonyl source and asparagine. Choosing a relatively higher storage temperature (Chuda et al., 2003) can reduce the content of reducing sugars in potatoes, thus reduce the acrylamide level in the final product. For processing conditions, an appropriate heating temperature should be set and long-time processing of the foodstuff should be avoided (Mottram et al., 2002). As for exogenous additives, many substances are reported to be effective for the mitigation of acrylamide, including some organic acids (*e.g.* citric acid, Cook & Taylor, 2005), some amino acids (*e.g.* glycine, Claeys, De Vleeschouwer, & Hendrickx, 2005), and some mono- and divalent cations (*e.g.* Na^+ or Ca^{2+}, Gökmen & Senyuva, 2007). We can refer to Zhang and Zhang (2007), Friedman and Levin (2008), Zhang, Ren, and Zhang (2009) or Capuano and Fogliano (2011) for comprehensive, detailed and also up-to-date reviews.

The Confederation of the Food and Drink Industries of the EU (French: Confédération des Industries Agro-Alimentaires de l'UE; CIAA) summarized the research progress on the reduction of acrylamide and listed the parameters that influence the final level of acrylamide, creating the "CIAA Toolbox" in 2005. This toolbox was recently updated in Sep. 2011. The newly updated parameters for potato-based products included agronomical factors (sugars & asparagine), recipe factors (fermentation, dilution and piece size, pH, other minor ingredients such as amino acids and calcium salts), processing factors (asparaginase, thermal input & moisture, pre-treatment and finished product color) and final preparation factors (consumer preparation) (CIAA, 2011).

Among the parameters affecting the level of acrylamide in foods, the effect of antioxidants has not yet been elucidated satisfactorily. As a wide range of substances, the relationship between antioxidants and acrylamide formation deserves, however to be discussed.

2. Interesting results & questions asked

Previously, food researchers and technologists applied both antioxidative extracts and pure antioxidants to inhibit acrylamide generation. But both positive and negative results had been obtained. By reading and comparing the literature, interesting phenomena had drawn our attention.

2.1. Different effects of different antioxidants on acrylamide content

Rosemary, a spice with a known antioxidant property, had been proposed as one effective inhibitor of acrylamide. It was presented that acrylamide contents were lowered in fried potato slices when rosemary herb was added to either corn or olive oil (Becalski, Lau, Lewis, & Seaman, 2003). The above finding was confirmed by Hedegaard, Granby, Frandsen, Thygesen, and Skibsted (2008) who added aqueous rosemary extract, rosemary oil and dried rosemary leaves to a bread model, thus reduced the content of acrylamide by 62, 67 and 57%, respectively, compared to bread without rosemary. Zhu, Cai, Ke, and Corke (2009) applied 35 kinds of crude aqueous extracts of plants and 11 phenolic acids to mitigate acrylamide in an asparagine-glucose (ASN–GLC) model system, finding that 34 out of 35 plant extracts exerted reduction effect while 9 phenolic acids except for ferulic acid and hesperetin inhibited acrylamide formation.

On the other hand, another study reported that grape seed extract had no effect on acrylamide formation in bakery products using a crust-like model (Açar & Gökmen, 2009). Tareke (2003) also found out that the addition of commonly-used antioxidants like BHT, sesamol, and Vitamin E to meat before heating enhanced the formation of acrylamide.

Cheng, Shi, Ou, Wang, and Jiang (2010) tested six fruit extracts (from apple, blueberry, mangosteen, longan and dragon fruit with white or red flesh) for their activities against acrylamide formation, and found that apple extract demonstrated potent inhibitory effect, extracts of blueberry, mangosteen and longan had not shown significant impact, whereas dragon fruit extracts enhanced acrylamide formation.

2.2. Discordant effects of the same kind of antioxidant on acrylamide formation

One obvious example was about commonly consumed antioxidant ascorbic acid and its deviratives. Biedermann, Noti, Biedermann-Brem, Mozzetti, and Grob (2002) found a relatively weak reduction of the acrylamide formation by the addition of ascorbic acid to a potato model. Similar results were obtained by Levine and Smith (2005) when using ascorbic acid and ascorbate in a cracker model. However, by investigating the effect of ascorbyl palmitate and sodium ascorbate, Rydberg et al. (2003) found no effect on acrylamide net amount in a potato model.

Another example was about the use of two kinds of phenolic acids (caffeic and gallic acids) in two independent experiments (Bassama, Brat, Bohuon, Boulanger, & Günata, 2010; Kotsiou, Tasioula-Margari, Capuano, & Fogliano, 2011). Results obtained from the two experiments were completely the opposite: both phenolic acids were non-effective in reducing acrylamide in the former experiment but effective in the latter one.

2.3. Discordant effects between antioxidative extract and its representative components

We (Zhang & Zhang, 2008) showed that addition of two natural antioxidants, extract of bamboo leaves and extract of green tea, and also their representative components homoorientin and gallocatechin gallate (EGCG) to an ASN–GLC model system both significantly reduced acrylamide formation. Contrariwise, statistics showed that applying Virgin Olive Oil (VOO) extracts to a potato model system and fresh potatoes led to an enhanced level of acrylamide, while commonly-occurring phenols in VOO were proven to be effective in inhibiting acrylamide formation (Kotsiou, Tasioula-Margari, Kukurová, & Ciesarová, 2010).

These experimental facts seem confusing to some extent. Meanwhile, the questions that needed to be answered are raised as follows:

1. Why do different antioxidants have different effects?
2. Why does the same kind of antioxidant either inhibit or enhance acrylamide among laboratories?
3. Why does extract and its representative component behave differently?
4. Is antioxidant capacity involved?

In the rest of the article, we tried our best to summarize useful literature and come up with a possible explanation to the questions, with discussion about acrylamide formation mechanism and possible action of antioxidants involved.

3. Current understanding about acrylamide formation

Shortly after the discovery of acrylamide in foods, it has been established that the major pathway for acrylamide formation in foods is Maillard reaction with free asparagine as main precursor (Mottram et al., 2002; Stadler et al., 2002, 2004; Zyzak et al., 2003). Asparagine was proved to provide the backbone chain of acrylamide