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Addition of Antioxidant of Bamboo Leaves (AOB) Effectively Reduces Acrylamide Formation in Potato Crisps and French Fries

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The present study was to demonstrate the efficiency of antioxidant of bamboo leaves (AOB) on the reduction of acrylamide during thermal processing and to summarize the optimal level of AOB applied in potato-based products. Potato crisps and French fries were immersed into different contents of AOB solution, and the frying processing parameters were optimized. The acrylamide content was determined by liquid chromatography−tandem mass spectrometry (LC-MS/MS). The sensory evaluation was performed in double blind manner. Our results showed that nearly 74.1% and 76.1% of acrylamide in potato crisps and French fries was reduced when the AOB addition ratio was 0.1% and 0.01% (w/w), respectively. The maximum inhibitory rate was achieved when the immersion time was designed as 60 s. Sensory evaluation results showed that the crispness and flavor of potato crisps and French fries processed by AOB solution had no significant difference compared to normal potato matrixes ($P > 0.05$) when the AOB addition ratio was <0.5% (w/w). These results suggested that AOB could significantly reduce acrylamide formation in potato-based foods and keep original crispness and flavor of potato matrixes. This study could be regarded as a pioneer contribution on the reduction of acrylamide in various foods by natural antioxidants.

KEYWORDS: Acrylamide; potato crisps; French fries; reduction; antioxidant of bamboo leaves

INTRODUCTION

Acrylamide, a potential genetic and reproductive toxin with mutagenic and carcinogenic properties in experimental mammalians in both in vitro and in vivo study, has been found in a large range of fried and baked carbohydrate-rich foods, which has attracted worldwide concern (*1*). It has been demonstrated that asparagine, a major free amino acid in potatoes and cereals, is an important precursor in the formation of acrylamide via Strecker degradation mechanism of Maillard reaction (*2*, *3*). After the discovery of acrylamide formation in Maillard reaction, several hypotheses on formation pathways were discussed at the very early stages of investigations, focusing initially on vegetable oils or lipids, since the problem mainly encompassed carbohydrate-rich foods that are fried or baked. In general, some critical and direct precursors contributing to the formation of acrylamide were demonstrated as 3-aminopropionamide, decarboxylated schiff base (*4*), decarboxylated Amadori product (*5*), acrylic acid (*6*, *7*), and acrolein (*8*).

Ever since, it has been an urgent agenda to search effective ways to reduce the formation of acrylamide during heat processing. With the development of acrylamide formation studies, more and more researchers are involved in the reduction of acrylamide contaminant. Excitingly, various effective ways for the reduction of acrylamide have been found during these years such as change of precursors in food materials (*9*), change of heat-processing methods (*10*), optimization of suitable cultivar and storage temperature of food materials (*11*), fermentation (*12*), and so forth. However, this may be difficult to achieve in an industrial setting or during home preparation and will also be difficult to achieve in commercial products.

Some novel contributions indicated that different additives, such as acids, amino acids, proteins, or hydrogencarbonates, could effectively reduce the content of acrylamide (*13*−*15*). Reduction of pH also seems to reduce the acrylamide content (*16*, *17*). Jung et al. (*18*) hypothesized that if the free non-protonated amine is converted into non-nucleophilic protonated amine, the reaction of acrylamide formation would be effectively blocked. The conversion of free non-protonated amine to protonated amine is readily obtained by lowering pH of the reaction system. Bråthen et al. (*19*) found that addition of glycine during doughmaking significantly reduced acrylamide ranging from 50 to >90% and from 60% to >95% in flat breads and bread crusts, respectively. However, it is unknown whether such addition pretreatments induce unexpected flavor to the final products.

Antioxidant of bamboo leaves (AOB), a pale brown powder extracted from bamboo leaves, was capable of blocking chain reactions of lipid autoxidation, chelating metal ions of transient state, scavenging nitrite compounds, and blocking the synthetic

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reaction of nitrosamine testified by our previous study (*20*). Another previous study reported the main components and monomers in AOB and demonstrated its edible safety in due course (*21*). Moreover, AOB was testified to be a stronger antioxidant activity and inhibitory efficacy on transition-metal ion and free-radical-induced deterioration of macromolecules in vitro (*22*). Subsequently, AOB has been listed in the national standards, that is, GB-2760, as a kind of food antioxidant in China. In addition, it has the permission of being added into the puffed food, fish, and meat products and edible oils authorized by Ministry of Health, P. R. China. The main functional components in AOB are flavonoids, lactones, and phenolic acids. As for the flavonoids in AOB, flavone *C*-glucosides are a group of representative flavonoids in AOB reported by Zhang et al. (*23*). Addition of plant extracts in various products to exert their characteristic effects is a novel and possible technique for limitation of acrylamide in corresponding products. Becalski et al. (*24*) found that acrylamide could be reduced when adding rosemary herb to the oil used for frying potato slices. Similarly, nearly 50% reduction of acrylamide after the addition of a flavonoid spice mix has also been reported by Fernández et al. (*25*). Biedermann et al. (*26*) showed a weak inhibition of the acrylamide formation by the addition of ascorbic acid in a potato-based model.

Thus, the aim of this study was to investigate the possibility of reducing the content of acrylamide in potato-based foods by immersion of products in AOB solutions before frying and to summarize the optimal level of AOB applied in selected food matrixes.

MATERIALS AND METHODS

Chemicals. Acrylamide (99%) and $^{13}C_3$-labeled acrylamide (isotopic purity 99%) were purchased from Sigma-Aldrich (St. Louis, MO) and Cambridge Isotope Laboratories (Andover, MA), respectively. Formic acid (96%) was obtained from Tedia (Fairfield, OH) while methanol (HPLC-grade) was supplied by Merck (Whitehouse Station, NJ). All other solvents and chemicals used for the determination of acrylamide were of analytical grade.

Raw Materials. The potato variety Atlantic supplied by Shanghai Pepsi Co. Ltd. (Shanghai, China) was used for the production of potato crisps. After harvest, the tubers were stored for 1 month at 8 °C and before the experiment at 4 °C for 1 month. The quick-frozen potato bars with the similar dimensions (8 mm × 8 mm × 80−100 mm) purchased from Shanghai Songshen Marine Product Co. Ltd. (Shanghai, China) were used for the production of French fries. All potatoes and processing products came from specialized farms in China.

Preparation of AOB. AOB was prepared from the bamboo leaves of *Phyllostachys nigra* var. *henonis* identified by Research Institute of Subtropical Forestry of the Chinese Academy of Forestry (Hangzhou, China). Briefly, fresh bamboo leaves were collected during the autumn season in Anji district (Zhejiang Province, China) and were air-dried. The coarse powder of bamboo leaves was obtained by crashing into the size of 20−40 mesh and 10 g powder was extracted by 100 mL 30% (v/v) ethanol aqueous solution and was refluxed for about 1 h. The filtrate was then isolated by membrane filtration to remove macro- and micromolecular components such as polysaccharides and minerals, and AOB was finally obtained after concentrating in vacuum and spray drying. The full-sample analysis data of AOB including the content of flavonoid, lactone, and phenolic acid monomer were reported in our previous study (*21*).

Preparation of Potato Crisps and French Fries. For the preparation of potato crisps, fresh potato tubers were washed, peeled, and sliced to a thickness of about (1.2 ± 0.2) mm. Alternatively, for the preparation of French fries, commercial potato bars were washed by warm water to flush away the coated fat. Both the potato slices and the fat-removed bars were washed twice by hand under running water and were dried between two adsorbent papers. Then, two pretreated materials in respective test groups were both immersed in a prepared solution containing 0.001%, 0.01%, 0.05%, 0.1%, 0.5%, and 1% (w/w) AOB while the slices and bars in the control group were immersed in distilled water. At the end of immersing, the slices and bars in all of the experimental groups were then oven-dried at 50 °C for about 30 min. After drying, both the control group and six test groups of potato slices and bars were loaded in a heating basket, which was large enough to ensure free movement of the fried materials in the frying oil, and were fried in palm oil, as (55 ± 5) g batches, for exactly 4 min at (170 ± 1) °C in a 10 L electric frying pan (Rui'an, Zhejiang, China). The potato-to-oil weight ratio was deliberately maintained low to stabilize the actual frying temperature (170 ± 1) °C according to the method of Mestdagh et al. (*27*). Each batch of both materials was separately fried in fresh oil, and then the batches were thoroughly mixed together. Finally, all potato crisps and French fried products were then submitted for quantitative analysis of acrylamide. The experiments were performed in sextuple repeats ($n = 6$).

Table 1. Score Criteria on the Sensory Evaluation of Potato Crisps and French Fries

evaluation index	score	description
color	4–5 point	natural pale yellow or golden and nearly no maculae
	2–3 point	dark yellow or pale brown and a few maculae
	0–1 point	dark brown and many maculae
crispness	4–5 point	crisp and homogeneous texture, little oil in the surface
	2–3 point	a bit crisp and homogeneous texture, a little oil in the surface
	0–1 point	soft and non-homogeneous texture
flavor	4–5 point	characteristic potato flavor and no undesirable taste
	2–3 point	characteristic potato flavor but not very obvious, and a little undesirable taste
	0–1 point	no characteristic potato flavor and undesirable bitter taste

Optimization of Immersion Time during Preparation. During the whole processing of potato crisps and French fries, immersion time is an important factor and directly affects the absorption of AOB. To testify the relationship between the immersion time and the concentration of acrylamide formation, the parallel-processed potato crisps and French fries ($n = 3$) were immersed 5, 15, 30, 60, 300, and 600 s in 0.01% (w/w) of prepared AOB solution. Meanwhile, the control groups for both potato crisps and French fries, which were immersed 0, 5, 15, 30, 60, 300, and 600 s in distilled water, were also performed. Here, both potato products were selected for the optimization study on immersion time because of the inherent complexity of food matrixes, where various factors were involved that acted one upon another.

Measurement of Moisture Contents. The moisture contents of two potato-based foods prepared with different immersion times were routinely determined by oven-drying according to Elmore et al. (*28*) with minor modifications. Briefly, samples (~3 g) were weighed accurately into predried and weighed metal oven-drying dishes. The weight losses after heating at 120 °C for 1 h in a fan oven were recorded. The samples were then heated for a further hour at 120 °C, were allowed to cool, and were reweighed. Three replicates were performed for each sample. Moisture losses in potato-based foods were determined by weighing the potato slices and potato bars directly before and immediately after frying. Potato crisps and French fries were allowed to cool and then were weighed again before they were ground and submitted for analysis. The moisture contents of fried potato products were also used to calculate the concentrations of acrylamide on a dry weight basis.

Sample Pretreatment and Acrylamide Quantification by Liquid Chromatography−Tandem Mass Spectrometry (LC-MS/MS). The quantification of acrylamide was based on the pretreatment of potato products and was performed on LC-MS/MS with electrospray positive ionization (ESI+) using a Micromass Quattro Ultima coupled to Waters 2695 HPLC with an Atlantis dC$_{18}$ column (210 × 1.5 mm, 5 μm; Waters, Milford, MA) according to our previous published methods (*29*−*31*). Briefly, as for the sample pretreatment, prepared potato crisps

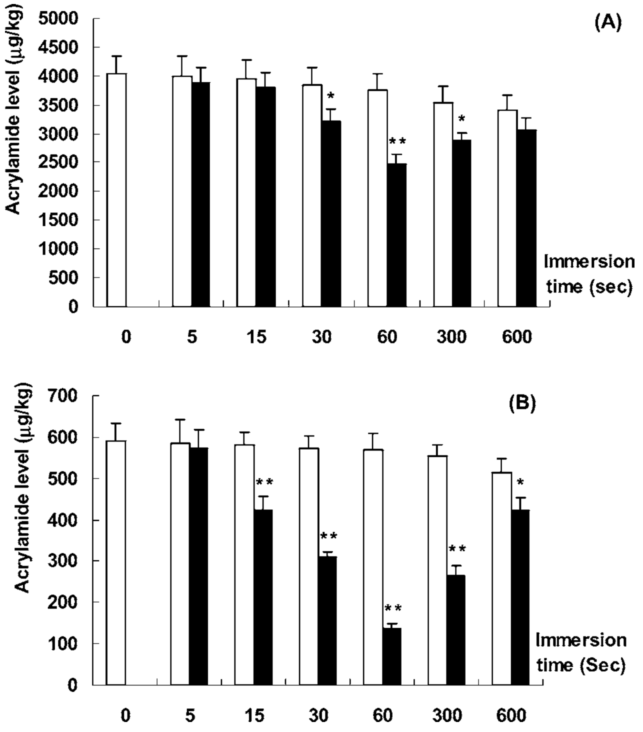

Figure 1. Acrylamide formation in (**A**) potato crisps and (**B**) French fries treated with different immersion times and compared to the control group ($n = 3$). □, control group; ■, 0.01% AOB treated group. **, $P < 0.01$; *, $P < 0.05$.

and French fries in each group were sampled, spiked with $^{13}C_3$-acrylamide (internal standard), defatted with petroleum ether, extracted with 2 mol L^{-1} aqueous solution of sodium chloride, further liquid−liquid extracted with ethyl acetate, and purified by solid-phase extraction (SPE) with OASIS HLB cartridges (6 mL, 200 mg) purchased from Waters Technology (Milford, MA). Oasis HLB SPE cartridges (6 cm^3, 200 mg) were conditioned with 3.5 mL of methanol followed by 3.5 mL of water; the methanol and water portions were discarded. Each cartridge was loaded with 1.5 mL of redissolved extract. The extract was allowed to pass through the sorbent material and was discarded. Then, the cartridge was eluted with 3 mL of water, and the eluant was collected. Finally, the analyte after cleanup was submitted for LC-MS/MS analysis, with ESI+ and three injections of each sample. The optimal LC and MS/MS parameters were used according to previous study (*30*). The analysis was integrated within the scope of an authorized proficiency test controlled by the official Food Analysis Performance Assessment Scheme (FAPAS) for accreditation. The optimized LC-MS/MS method was validated in-house via linearity, retention time, limit of detection (LOD), limit of quantification (LOQ), repeatability, and recovery, which were reported in our previous publication (*30*). Compared to the level (1404 μg kg^{-1}) reported by the organization, the result from our laboratory (No. 021) for acrylamide (1381 μg kg^{-1}) in dispatched test material with a Z-score of −0.1 seemed satisfactory, which fulfills requirements from the organization (*32*).

Sensory Analysis. Thirty untrained volunteers were invited to score samples from the control and test groups in terms of color, crispness, flavor, and overall acceptability for hedonic studies. Samples in each test group via immersion in the different level of AOB solution were compared with counterparts in the control group. The sensory analysis was performed in double blind manner to eliminate the effect of subjective prejudice. The score criteria of potato crisps and French fries in each group were presented in **Table 1**.

Statistical Analysis. Experimental data from acrylamide analysis were shown as mean ± SD while statistical analysis was performed by Duncan's multiple comparison tests and paired Student's *t*-test to determine the significance differences for treatment means of acrylamide formation and sensory evaluation results in different treatments.

Table 2. Moisture Contents of Potato Slices and Potato Bars Directly before and Immediately after Frying

	moisture content (%)[a]			
	potato slices		potato bars	
immersion time (s)	before frying	after frying	before frying	after frying
5	59.5	13.7	50.7	26.4
15	61.4	16.4	55.4	23.7
30	66.9	8.8	56.7	28.6
60	70.6	16.3	63.5	33.0
300	72.5	13.0	64.0	30.2
600	74.0	12.1	67.9	26.1

[a] The frying time of both potato materials was 4 min.

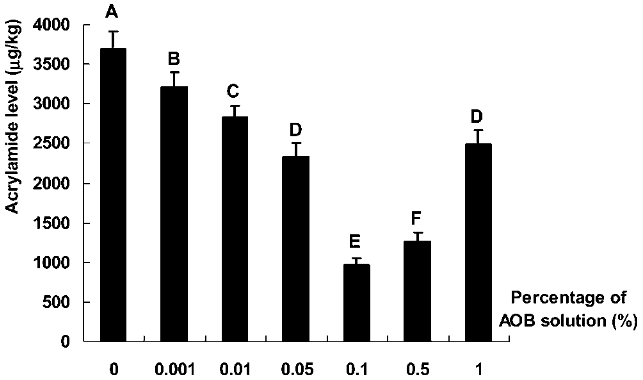

Figure 2. Relationship between acrylamide levels and different conditions of AOB immersion treatment in potato crisps (immersion time: 60 s, $n = 6$). Error bars designate standard deviation (SD) and different letters designate significant differences via Duncan's multiple comparison ($P < 0.05$).

RESULTS AND DISCUSSION

Optimization of Immersion Time and Quantification of Moisture Contents. Figure 1 shows the acrylamide formation in potato crisps and French fries treated with different immersion times compared to the control group. As for potato crisps, 0.01% AOB treated samples immersed 5, 15, 30, 60, 300, and 600 s contained 3888.7 ± 256.8, 3794.6 ± 269.8, 3211.5 ± 222.5, 2476.9 ± 165.5, 2877.0 ± 143.3, and 3064.4 ± 220.3 μg kg^{-1} of acrylamide ($n = 3$), which indicated that six different treatments induced 2.5%, 4.1%, 16.6%, 34.0%, 18.8%, and 10.3% inhibition of acrylamide formation, respectively. The acrylamide content of potato crisps with the 60-s immersion treatment was significantly different from that of the controls immersed the same time in water ($P < 0.01$). On the other hand, the preparation of French fries with such treatments contained 573.1 ± 44.6, 423.7 ± 31.7, 310.4 ± 11.8, 135.5 ± 13.5, 264.3 ± 23.4, and 423.5 ± 29.9 μg kg^{-1} of acrylamide ($n = 3$), which induced 2.1%, 27.3%, 45.7%, 76.1%, 52.3%, and 17.5% inhibition of acrylamide generation, respectively. The acrylamide content of French fries with the 15, 30, 60, and 300 s immersion treatments was significantly different from that of corresponding control groups ($P < 0.01$). Considering the reduction efficiency on acrylamide, 60 s was chosen as the optimized immersion time during the preparation of potato crisps and French fries in the further experiments.

Interestingly, the acrylamide level in both samples in the control group slightly decreased with the increase of immersion time during the treatment (**Figure 1**). Such results may be related to the change of acrylamide precursor concentrations such as

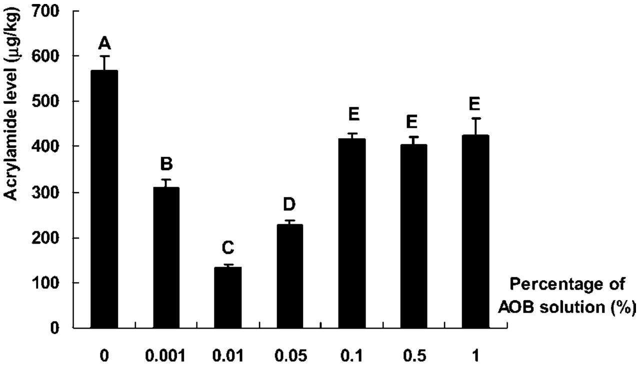

Figure 3. Relationship between acrylamide levels and different conditions of AOB immersion treatment in French fries (immersion time: 60 s, $n = 6$). Error bars designate standard deviation (SD) and different letters designate significant differences via Duncan's multiple comparison ($P < 0.05$).

Table 3. Sensory Results of Potato Crisps in Different Groups ($n = 30$)[a]

	percentage of AOB treatment solution (%)						
	control	0.001	0.01	0.05	0.1	0.5	1
			Color				
mean score	4.43	4.50	4.26	4.13	4.06*	1.73**	ND
P value		0.536	0.231	0.107	0.019	0.000	ND
			Crispness				
mean score	4.23	4.00	3.87	4.13	3.87	2.90**	ND
P value		0.457	0.102	0.522	0.054	0.000	ND
			Flavor				
mean score	4.16	4.13	3.93	3.97	3.90	3.00**	ND
P value		0.861	0.282	0.312	0.187	0.000	ND

[a] ND, the potato crisps treated with 1% AOB were not evaluated because they were thoroughly unacceptable. *, $P < 0.05$; **, $P < 0.01$.

Table 4. Sensory Results of French Fries in Different Groups ($n = 30$)[a]

	percentage of AOB treatment solution (%)						
	control	0.001	0.01	0.05	0.1	0.5	1
			Color				
mean score	4.70	4.60	4.60	4.37	4.43*	2.13**	ND
P value		0.448	0.375	0.057	0.018	0.000	ND
			Crispness				
mean score	4.37	4.17	4.17	4.13	4.03	3.83*	ND
P value		0.506	0.296	0.129	0.134	0.011	ND
			Flavor				
mean score	4.37	4.27	4.07	4.10	4.03	3.23**	ND
P value		0.557	0.130	0.088	0.057	0.000	ND

[a] ND, the French fries treated with 1% AOB were not evaluated because they were thoroughly unacceptable. *, $P < 0.05$; **, $P < 0.01$.

glucose and asparagine in food matrixes, which suggested that the water-immersing process leads to a higher leaching of important acrylamide precursors that finally results in lower acrylamide formation (*33*). Fiselier and Grob (*9*) found that a suitable limit for the reducing sugars in the prefabricates for French fries is a simple and efficient measure to reduce the exposure to acrylamide from the predominant source for many consumers. Haase et al. (*34*) also reported that a reduction of the sugar content by blanching could reduce the acrylamide concentration by about 60% according to the raw material and the production process variables (e.g., blanching conditions and frying temperatures). As for the acrylamide content of potato products with AOB treatments, it was easy to understand that a short immersion time might not lead to significant effects on the acrylamide content because AOB might not be fully penetrated into the potato materials within a short immersion time (<60 s). When the immersion treatment was performed longer than 60 s, effects on the reduction of acrylamide in both matrixes seemed dramatically weaker with the increase of immersion time. In other words, compared to the control groups, the acrylamide level in both potato crisps and French fries enhanced significantly when the two products were treated by 0.01% of AOB aqueous solution with increased immersion time. The moisture contents of potato slices and potato bars directly before and immediately after frying are shown in **Table 2**. Results indicated that the treatment of potato products with a relatively long immersion time may increase their moisture contents and slightly reduce the acrylamide level during frying. Few studies have been carried out on the effect of moisture content on acrylamide formation. Leung et al. (*35*) measured water loss in a fritter made from wheat flour, which was deep fried at 170 °C, 190 °C, or 210 °C. The original moisture content of the fritter was ∼48% and fell to ∼10% after 15 min at 170 °C; that is, over one-fifth of the original water in the fritter remained, at which time the acrylamide content was ∼200 μg kg^{-1}. Similar research demonstrated that the acrylamide formation did not occur to a large degree until the moisture contents of potato flake fell below 5% (*28*). Therefore, in our experiment it seems that the moisture content of both potato materials before frying was inversely proportional to acrylamide content, possibly because the oil surrounding the samples provided a barrier to diffusion of moisture from the surface of potato raw materials.

Comparison of Acrylamide Reduction among Different AOB Treatment Groups. The relationship between acrylamide levels and different conditions of AOB immersion treatment in potato crisps is shown in **Figure 2**. Results indicated that potato crisps with 0.001%, 0.01%, 0.05%, 0.1%, 0.5%, and 1% AOB treatments induced 14.8%, 25.1%, 38.1%, 74.1%, 66.5%, and 33.9% inhibition of acrylamide formation, respectively. The acrylamide contents in all AOB treated potato crisp groups were significantly different from that of the control group ($P < 0.01$). Duncan's multiple comparison tests showed that the acrylamide content among six AOB treated groups and one control group was also significantly different from each other ($P < 0.05$) except the acrylamide level between 0.05% and 1% AOB treated groups ($P > 0.05$). To our surprise, a positive and negative AOB concentration-dependent relationship of acrylamide inhibitory rate occurred with the AOB treatment range of 0.001−0.1% and 0.1−1%, respectively. The 0.1% AOB treatment could be regarded as the critical effective concentration.

On the other hand, the relationship between acrylamide levels and different conditions of AOB immersion treatment in French fries is shown in **Figure 3**. Results demonstrated that French fries with 0.001%, 0.01%, 0.05%, 0.1%, 0.5%, and 1% AOB treatments led to 44.6%, 76.1%, 59.2%, 25.5%, 27.5%, and 24.0% reduction of acrylamide formation, respectively. The acrylamide contents in all AOB treated potato crisp groups were significantly different from that of the control group ($P < 0.01$). Duncan's multiple comparison tests showed that the acrylamide content among the 0.001%, 0.01%, and 0.05% AOB treated groups and the control group was also significantly different from each other ($P < 0.05$) except the acrylamide level between 0.1%, 0.5%, and 1% AOB treated groups ($P > 0.05$). Similarly, a positive AOB concentration-dependent relationship of acrylamide inhibitory rate occurred with the AOB treatment range of 0.001−0.01%. The 0.01% AOB treatment in French fries could be regarded as the best effective concentration.

Results of acrylamide contents in both potato crisps and French fries showed the opposite concentration-dependent relationships in different ranges of AOB treatments, even though no significant concentration-dependent relationship was present in French fries in high ranges of AOB treatment. Such reverse tendency on the reduction of acrylamide may relate to the inherent property of antioxidants and the antioxidant activity of food matrixes, which is something called "antioxidative paradox". Summa et al. (*36*) found a direct correlation between the concentration of acrylamide and the antioxidant activity in self-prepared cookies and demonstrated that the combined conditions including long baking time, high protein content in samples, and low moisture could simultaneously increase the acrylamide level and the antioxidant activity. However, it does not mean that an inevitable forward or backward relationship is present between the reduction efficiency of acrylamide and the antioxidant activity of food matrixes. In fact, the possible role of lipids used for frying systems during the acrylamide formation has induced an intensive controversy. One hypothetical mechanism contributing to the acrylamide formation is via acrolein pathway, formed from the degradation of lipids, mainly oxidized fatty acids or glycerol. Lipids heated at high temperature can lead to the formation of acrolein (*37*). Acrolein can further react via oxidation to generate acrylic acid or by formation of an intermediate acrylic radical (*6*). Both of the intermediates could then induce acrylamide formation in the presence of a nitrogen source under favorable reaction conditions (*8*). Therefore, theoretically speaking, addition of antioxidants could block the oxidation of acrolein to a certain extent and further reduce the generation of acrylamide. Some previously published contributions demonstrated such a hypothesis in potato-based foods (*24*−*26*, *38*). In the present work, sufficient evidence demonstrated that potato crisps and French fries with AOB treatments have decreasing levels of acrylamide compared to the food without any treatment, accompanying the phenomenon of antioxidative paradox.

Sensory Evaluation of Potato Products with AOB Treatments. In general, when research focuses on the reduction of acrylamide generated in the Maillard reaction via addition of exogenous chemical additives, we should comply with the following acknowledged conditions: (1) The addition level should be properly controlled according to corresponding criteria of food or chemical additives. (2) The selected additives should be regarded as no toxicity was demonstrated by toxicity test from previous publications. (3) The additives applied to the food systems cannot affect the connatural and sensory characteristics of processing foods. As the problems of addition levels and toxicity of AOB were solved in the above section and our previous study (*21*), the main challenge will be to achieve substantial reduction of acrylamide while keeping desirable product sensory attributes such as flavor and color, which are generated by similar Maillard reaction pathways.

The sensory results of potato crisps in different groups are shown in **Table 3**. The crispness and flavor of potato crisps processed by AOB solution had no significant difference compared to normal food matrixes ($P > 0.05$) when the AOB addition ratio was <0.5% (w/w), while the color of samples could be regarded as no obvious change ($P > 0.05$) when the AOB treatment level was in the range 0.001−0.05% (w/w). However, the color of samples in 0.1% AOB treatment groups and all the three sensory indexes of samples in 0.5% AOB showed great discrepancy compared to the control ($P < 0.05$, $P < 0.01$). Furthermore, the sensory attributes of potato crisps with 1% AOB treatments could not be acceptable. Similar sensory evaluation was obtained from the French fries in different groups (**Table 4**). Considering the combined factors of inhibitory effect and sensory acceptance, the potato crisps and French fries should be treated with 0.1% and 0.01% AOB solution via immersion, respectively, which would not only effectively achieve the reduction of acrylamide but would also retain reasonable sensory attributes. Nowadays, many researchers (*18*, *39*) have found effective ways to reduce acrylamide during heat processing, some of which were also performed via immersion, but their sensory evaluation was not reported or not very reasonable or even not acceptable. For instance, Kita et al. (*16*) found that the largest decrease of acrylamide content (90%) in French fries was achieved when potato slices were soaked in acetic acid solution for 60 min at 20 °C, and a large decrease of acrylamide content (74%) was also observed after soaking of potato slices in 1% NaOH solution. However, a sour and acerbic taste from both treatments greatly influenced the appearance as well as the taste and flavor of French fries, which were not sensorially acceptable (*16*). In the present work, although the optimal inhibitory rate of acrylamide in both potato-based samples was a bit lower than some other published methods, the balance between reduction and sensory acceptance was well achieved.

Our findings in the present study show that the addition of AOB effectively reduces the amounts of acrylamide in potato crisps and French fries. The optimal method on AOB treatments could not only effectively achieve the reduction of acrylamide but could also retain reasonable sensory attributes. This study could be regarded as a pioneer finding of an effective, simple, and practical way to reduce acrylamide formation in potato-based foods by natural antioxidants. However, the mechanism of acrylamide reduction by AOB including the reduction pathway, identification, and quantification of acrylamide precursors relates their presence to a possible chemical mechanism of action, and generation of new intermediates or site products in the Maillard reaction still remains to be clarified and will be conducted in due course. Meanwhile, the effects of acrylamide reduction on other fried or baked products via the addition of AOB are necessarily investigated further.

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LITERATURE CITED

(1) Tareke, E.; Rydberg, P.; Karlsson, P.; Eriksson, S.; Törnqvist, M. Analysis of acrylamide, a carcinogen formed in heated foodstuffs. *J. Agric. Food Chem.* **2002**, *50*, 4998−5006.

(2) Mottram, D. S.; Wedzicha, B. L.; Dodson, A. T. Acrylamide is formed in the Maillard reaction. *Nature* **2002**, *419*, 448−449.

(3) Stadler, R. H.; Blank, I.; Varga, N.; Robert, F.; Hau, J.; Guy, P. A.; Robert, M. -C.; Riediker, S. Acrylamide from Maillard reaction products. *Nature* **2002**, *419*, 449−450.

(4) Zyzak, D. V.; Sanders, R. A.; Stojanovic, M.; Tallmadge, D. H.; Eberhart, B. L.; Ewald, D. K.; Gruber, D. C.; Morsch, T. R.; Strothers, M. A.; Rizzi, G. P.; Villagran, M. D. Acrylamide formation mechanism in heated foods. *J. Agric. Food Chem.* **2003**, *51*, 4782−4787.

(5) Yaylayan, V. A.; Wnorowski, A.; Locas, C. P. Why asparagine needs carbohydrates to generate acrylamide. *J. Agric. Food Chem.* **2003**, *51*, 1753−1757.

(6) Becalski, A.; Lau, B. P. -Y.; Lewis, D.; Seaman, S. W. Acrylamide in foods: occurrence, sources, and modeling. *J. Agric. Food Chem.* **2003**, *51*, 802−808.

(7) Stadler, R. H.; Verzegnassi, L.; Varga, N.; Grigorov, M.; Studer, A.; Riediker, S.; Schilter, B. Formation of vinylogous compounds in model Maillard reaction systems. *Chem. Res. Toxicol.* **2003**, *16*, 1242−1250.

(8) Yasuhara, A.; Tanaka, Y.; Hengel, M.; Shibamoto, T. Gas chromatographic investigation of acrylamide formation in browning model systems. *J. Agric. Food Chem.* **2003**, *51*, 3999−4003.

(9) Fiselier, K.; Grob, K. Legal limit for reducing sugars in prefabricates targeting 50 μg/kg acrylamide in French fries. *Eur. Food Res. Technol.* **2005**, *220*, 451−458.

(10) Granda, C.; Moreira, R. G.; Tichy, S. E. Reduction of acrylamide formation in potato chips by low-temperature vacuum frying. *J. Food Sci.* **2004**, *69*, E405−E411.

(11) Biedermann-Brem, S.; Noti, A.; Grob, K.; Imhof, D.; Bazzocco, D.; Pfefferle, A. How much reducing sugar may potatoes contain to avoid excessive acrylamide formation during roasting and baking? *Eur. Food Res. Technol.* **2003**, *217*, 369−373.

(12) Fredriksson, H.; Tallving, J.; Rosén, J.; Åman, P. Fermentation reduces free asparagine in dough and acrylamide content in bread. *Cereal Chem.* **2004**, *81*, 650−653.

(13) Amrein, T. M.; Schönbächler, B.; Escher, F.; Amadò, R. Acrylamide in gingerbread: critical factors for formation and possible ways for reduction. *J. Agric. Food Chem.* **2004**, *52*, 4282−4288.

(14) Claeys, W. L.; de Vleeschouwer, K.; Hendrickx, M. E. Effect of amino acids on acrylamide formation and elimination kinetics. *Biotechnol. Prog.* **2005**, *21*, 1525−1530.

(15) Vattem, D. A.; Shetty, K. Acrylamide in food: a model for mechanism of formation and its reduction. *Innovations Food Sci. Emerging Technol.* **2003**, *4*, 331−338.

(16) Kita, A.; Bråthen, E.; Knutsen, S. H.; Wicklund, T. Effecitive ways of decreasing acrylamide content in potato crisps during processing. *J. Agric. Food Chem.* **2004**, *52*, 7011−7016.

(17) Rydberg, P.; Eriksson, S.; Tareke, E.; Karlsson, P.; Ehrenberg, L.; Törnqvist., M. Investigations of factors that influence the acrylamide content of heated foodstuffs. *J. Agric. Food Chem.* **2003**, *51*, 7012−7018.

(18) Jung, M. Y.; Choi, D. S.; Ju, J. W. A novel technique for limitation of acrylamide formation in fried and baked corn chips and in French fries. *J. Food Sci.* **2003**, *68*, 1287−1290.

(19) Bråthen, E.; Kita, A.; Knutsen, S. H.; Wicklund, T. Addition of glycine reduces the content of acrylamide in cereal and potato products. *J. Agric. Food Chem.* **2005**, *53*, 3259−3264.

(20) Lou, D. D.; Zhang, Y.; Wu, X. Q.; Qi, J. J.; Zhuo, Y. X. Application of antioxidant of bamboo leaves (AOB) in Weixin western sausages. *Chin. Food Ferment. Ind.* **2004**, *30*, 13−17.

(21) Lu, B. Y.; Tie, X. W.; Wu, X. Q.; Zhang, Y.; Zhang, Y. Toxicology and safety of anti-oxidant of bamboo leaves. Part I: Acute and subchronic toxicity studies on anti-oxidant of bamboo leaves. *Food Chem. Toxicol.* **2005**, *43*, 783−792.

(22) Hu, C.; Zhang, Y.; Kitts, D. D. Evaluation of antioxidant and prooxidant activities of bamboo *Phyllostachys nigra* var. *Henonis* leaf extract *in vitro*. *J. Agric. Food Chem.* **2000**, *48*, 3170−3176.

(23) Zhang, Y.; Bao, B. L.; Lu, B. Y.; Ren, Y. P.; Tie, X. W.; Zhang, Y. Determination of flavone C-glucosides in antioxidant of bamboo leaves (AOB) fortified foods by reversed-phase high-performance liquid chromatography with ultraviolet diode array detection. *J. Chromatogr., A* **2005**, *1065*, 177−185.

(24) Becalski, A.; Lau, B. P. -Y.; Lewis, D.; Seaman, S. *Acrylamide in foods; Occurrence and sources*, Association of Official Analytical Chemists (AOAC) Annual Meeting, Los Angeles, CA, September 22−26, 2002.

(25) Fernández, S.; Kurppa, L.; Hyvönen, L. Content of acrylamide decreased in potato chips with addition of a proprietary flovoniod spice mix (Flavomare®) in frying. *Innovation Food Technol.* **2003**, 24−26.

(26) Biedermann, M.; Noti, A.; Biedermann-Brem, S.; Mozzetti, V.; Grob, K. Experiments on acrylamide formation and possibilities to decrease the potential of acrylamide formation in potatoes. *Mitt. Lebensmittelunters. Hyg.* **2002**, *93*, 668−687.

(27) Mestdagh, F. J.; de Meulenaer, B.; van Poucke, C.; Detavernier, C.; Cromphout, C.; van Peteghem, C. Influence of oil type on the amounts of acrylamide generated in a model system and in French fries. *J. Agric. Food Chem.* **2005**, *53*, 6170−6174.

(28) Elmore, J. S.; Koutsidis, G.; Dodson, A. T.; Mottram, D. S.; Wedzicha, B. L. Measurement of acrylamide and its precursors in potato, wheat, and rye model systems. *J. Agric. Food Chem.* **2005**, *53*, 1286−1293.

(29) Jiao, J. J.; Zhang, Y.; Ren, Y. P.; Wu, X. Q.; Zhang, Y. Development of a quantitative method for determination of acrylamide in infant powdered milk and baby foods in jars using isotope dilution liquid chromatography/electrospray ionization tandem mass spectrometry. *J. Chromatogr., A* **2005**, *1099*, 198−202.

(30) Zhang, Y.; Jiao, J. J.; Ren, Y. P.; Wu, X. Q.; Zhang, Y. Determination of acrylamide in infant cereal-based foods by isotope dilution liquid chromatography coupled with electrospray ionization tandem mass spectrometry. *Anal. Chim. Acta* **2005**, *551*, 150−158.

(31) Ren, Y. P.; Zhang, Y.; Jiao, J. J.; Cai, Z. X.; Zhang, Y. A sensitive isotope dilution liquid chromatography/electrospray ionization tandem mass spectrometry method for determination of acrylamide in chocolate. *Food Addit. Contam.* **2006**, *23*, 228−236.

(32) FAPAS Acrylamide Report 3011, 2005, FAPAS proficiency testing April. http://www.fapas.com/ fapas.cfm, accessed April 22, 2005.

(33) Pedreschi, F.; Kaack, K.; Granby, K. Acrylamide content and color development in fried potato strips. *Food Res. Int.* **2006**, *39*, 40−46.

(34) Haase, N. U.; Matthäus, B.; Vosmann, K. Acrylamide formation in foodstuffs − Minimising strategies for potato crisps. *Dtsch. Lebensm.−Rundsch.* **2003**, *99*, 87−90.

(35) Leung, K. S.; Lin, A.; Tsang, C. K.; Yeung, S. T. K. Acrylamide in Asian Foods in Hong Kong. *Food Addit. Contam.* **2003**, *20*, 1105−1113.

(36) Summa, C.; Wenzl, T.; Brohee, M.; de la Calle, B.; Anklam, E. Investigation of the correlation of the acrylamide content and the antioxidant activity of model cookies. *J. Agric. Food Chem.* **2006**, *54*, 853−859.

(37) Umano, K.; Shibamoto, T. Analysis of acrolein from heated cooking oils and beef fat. *J. Agric. Food Chem.* **1987**, *35*, 909−912.

(38) Taeymans, D.; Wood, J.; Ashby, P.; Blank, I.; Studer, A.; Stadler, R. H.; Gondé, P.; van Eijck, P.; Lalljie, S.; Lingnert, H.; Lindblom, M.; Matissek, R.; Müller, D.; Tallmadge, D.; O'Brien, J.; Thompson, S.; Silvani, D.; Whitmore, T. A review of acrylamide: an industry perspective on research, analysis, formation, and control. *Crit. Rev. Food Sci. Nutr.* **2004**, *44*, 323−347.

(39) Pedreschi, F.; Kaack, K.; Granby, K. Reduction of acrylamide formation in potato slices during frying. *LWT-Food Sci. Technol.* **2004**, *37*, 679−685.

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