Simultaneous inhibition of acrylamide and hydroxymethylfurfural formation by sodium glutamate microcapsules in an asparagine–glucose model system

Zimeng Wang¹ · Chao Wen¹ · Xingbo Shi¹ · Dai Lu¹ · Jiehong Deng¹ · Fangming Deng¹

Revised: 29 November 2016 / Accepted: 23 December 2016 / Published online: 6 January 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract Inhibiting the formation of acrylamide (AA) and hydroxymethylfurfural (HMF) during food heating processes has attracted considerable investigative efforts due to potential health concerns associated with these compounds. The main purpose of this work is to demonstrate a strategy to simultaneously inhibit the formation of AA and HMF with sodium glutamate microcapsules selected to confirm the efficacy of this strategy. An asparagine–glucose aqueous model system was prepared containing free sodium glutamate and sodium glutamate microcapsules. Compared to adding free sodium glutamate, the maximum inhibition efficiency for AA and HMF was found to increase by addition of sodium glutamate microcapsules to 19.07 and 84.32%, respectively. Moreover, the kinetics of AA and HMF formation were studied in this model system. The AA inhibition efficiency significantly increased from 6.75 to 60.35% and the HMF inhibition efficiency significantly increased from 5.98 to 79.72% with increasing the reaction time from 25 to 40 min, indicating that the sodium glutamate microcapsules strategy proves to be far superior at prolonged heating times. These findings suggested that this inhibition strategy may provide promising characteristics for a variety of applications in food processing.

Keywords Microcapsules · Inhibition efficiency · Sodium glutamate · Acrylamide · Hydroxymethylfurfural

Introduction

The Maillard reaction (MR), commonly taking place during the heating process of food, has attracted considerable attention in recent years. Various Maillard reaction products (MRPs) were reported to exhibit mutagenic, carcinogenic, or cytotoxic effects (Besaratnia and Pfeifer 2007; Hogervorst et al. 2010; Riboldi et al. 2014). Examples for such compounds include acrylamide (AA) and hydroxymethylfurfural (HMF). The International Agency for Research on Cancer (IARC) has identified AA as “possibly carcinogenic to humans” (IARC 1994), whereas HMF has been found to be cytotoxic, irritating to the eyes, skin, upper respiratory tract and mucous membranes (Capuano and Fogliano 2011).

Several mitigation strategies have been proposed to limit the formation of AA during food processing (Friedman and Levin 2008; Hidalgo et al. 2010; Liu et al. 2011; Shin et al. 2010; Xu et al. 2014; Zhu et al. 2016; Duda-Chodak et al. 2016). The addition of metal cations has been found to be an excellent strategy to inhibit AA formation (Açar et al. 2012; Göekmen and Senyuva 2007; Kalita and Jayanty 2013; Van der Fels-Klerx et al. 2014) and a variety of appropriate metal cations may serve as nutritional supplements in food. However, some methods described in the literature can promote the formation of HMF (Combs et al. 2013; Van der Fels-Klerx et al. 2014) with only a few reports addressing the inhibition of HMF formation or the simultaneous inhibition of AA and HMF formation. Numerous works focus on the Maillard Reaction factors, such as water activity (Miao et al. 2014), temperature, time

✉ Xingbo Shi
shixingbo123@aliyun.com

✉ Fangming Deng
fmdenghnau@sina.com

¹ Hunan Provincial Key Laboratory of Food Science and Biotechnology, College of Food Science and Technology, Hunan Agricultural University, Changsha 410128, Hunan, People's Republic of China

(Michalak et al. 2016), sugar type (Nguyen et al. 2016), etc. And they are interesting in how the factors affect the interaction effect between AA and HMF formation. Therefore, simultaneous inhibition of AA and HMF formation is a promising issue. Yeast fermentation was reported to be suitable for the mitigation of AA and HMF in instant coffee (Akillioglu and Gökmen 2014). However, this strategy proves to be vastly time-consuming and therefore unsuitable for adaptation to other food processing procedures.

The microencapsulation technique represents a strategy in which bioactive-molecules are embedded into small capsules, therefore lowering the release rate of bioactive molecules. This technique is widely used in food industry as it is able to delay potential oxidation and degradation processes of bioactive molecules during prolonged food processing (da Silva et al. 2014). Controlling the release rate of reactive or catalytic compounds during thermal treatment is expected to transform the reaction process and reduce the amount of undesired MRPs formed (Troise and Fogliano 2013). Fiore et al. (2012) first reported that NaCl encapsulation may reduce the HMF formation by 61% due to the inhibition of MRP key intermediates (3-deoxyglucosone, 3,4-dideoxyosone, fructofuranosyl cation). However, the addition of NaCl for encapsulation alters the flavor characteristics of a given food and generally does not improve the overall taste. Therefore, the addition of food flavor enhancers may prove to be more suitable. Sodium glutamate is widely used during food processing and sodium glutamate microcapsules may represent an attractive option to reduce the formation of MRPs through modulation of spontaneous pyrolytic sucrose decomposition reactions.

Herein, we report a microencapsulation strategy to simultaneously prevent the formation of AA and HMF in an asparagine–glucose aqueous model system. Sodium glutamate microcapsules were selected to verify the efficiency of this encapsulation strategy. For this purpose, different concentrations of the sodium glutamate microcapsules were added to the model system and the formation of HMF and AA was monitored at different reaction time points.

Materials and methods

Chemicals and materials

Acrylamide, HMF, glucose, L-asparagine and sodium glutamate were of analytical grade and were purchased from Sigma-Aldrich (Shanghai, China). HPLC grade methanol was purchased from Sinoparm Chemical Reagent Co Ltd. Ultrapure water (18.2 M Ω cm) was prepared using a milli-

Q purification-system (Millipore USA). Other reagents (glyceryl monostearate, carnauba wax, etc.) were of analytical grade and purchased from local reagent suppliers.

Preparation and analysis of microcapsules

In a typical experiment, 3.0 g sodium glutamate, 6.0 g carnauba wax and 1.50 g glycerol monostearate were dissolved in 600 mL ultrapure water. The mixed solution emulsified using a high-speed shear mulser (Y-25, Milwaukee, USA). The speed was set at 19,000 rpm for 30 min in a 60 °C water bath. Microencapsulation by spray-coating was performed using a SD-1500 spray dryer (Wo Di automation equipment Ltd., Shanghai). The inlet and outlet temperatures were set at 180 and 35 °C, respectively. A 60 mL/h feed rate was sprayed through a nozzle onto fluidized sodium glutamate to ensure fabrication of a smooth surface on the sodium glutamate microcapsules. The content of sodium glutamate in sodium glutamate microcapsules can be estimated by the percentage of sodium glutamate in microcapsules raw material.

The morphology of the microcapsules was studied by SEM (J8M-6380LV, JEOL, Japan). According to the morphology of the microcapsules, the size of the microcapsules could be determined. Conductivity experiments were carried out using a conductivity meter (DDS-30T, INESA, Shanghai). A sample of the microcapsules and sodium glutamate were loaded on a conductimeter cell containing 10.8 mL of ultrapure water. The conductivity was measured under agitation at a speed of 400 rpm for 40 min. A series of concentrations of sodium glutamate (0.50, 1.00, 1.50, 2.00, 2.50 mmol/L) was measured to obtain a standard curve. The concentrations of the sodium glutamate and microcapsule samples in solution were calculated in accordance to the conductivity of the solution.

Preparation of the asparagine–glucose aqueous model system

To study the effects of sodium glutamate microcapsules on the formation of AA and HMF, a reaction model consisting of asparagine and glucose was used. At the beginning, the different concentrations of sodium glutamate (10, 20, 30, 40, 50, 60 μ mol/L) aqueous solution were prepared. The reaction mixtures contained 1 mM asparagine and 1 mM glucose, with varying concentrations of sodium glutamate aqueous solution added, with a final volume of 200 μ L obtained by adding ultrapure water. Therefore, the content of sodium glutamate in the series of reaction mixtures is 0.102, 0.204, 0.306, 0.408, 0.510, 0.612 μ g/g. For the control group (water), 200 μ L water only was added. The Teflon vials containing the reaction mixtures were heated at 165 °C in a commercial oven for varying durations,

before being transferred to an ice-water bath. The sodium glutamate microcapsules prove to be difficult to dissolve in water. Therefore, the weight of sodium glutamate microcapsules containing the corresponding amount of sodium glutamate was added in practice.

AA and HMF analysis

The reaction mixtures in the Teflon vials were dilute by 100 mL ultrapure water and shaken vigorously for 3 min by a Vortex Vibrator. The mixture solutions were centrifuged at 5000g for 5 min at room temperature. The supernatant was then collected and filtered through a 0.45 μm nylon membrane. The prepared filtrate were utilized for analysis of AA and HMF. A Waters e2695 HPLC system (Milford, Massachusetts, USA) equipped with a e2998 diode array detector was used to analyze the concentration of AA and HMF. Ten microliters of a sample solution were injected into a symmetry-C18 column (4.6 mm $\times$ 250 mm, 5.0 μm) and eluted using 10% methanol in water with a flow rate of 0.8 mL/min at 30 $^{\circ}\text{C}$. The concentration of AA and HMF could be simultaneously detected by monitoring the 197 nm and 283 nm chromatographic absorption peaks. In this experiment condition, the AA and HMF retention time is 4.565 and 10.32 min, respectively. All mobile phases were degassed prior to injection by using an ultrasonicator and were filtered through 0.45 μm membranes. A series of concentrations of AA (5, 10, 15, 20, 25 $\mu\text{mol/L}$) and HMF (1, 5, 10, 15, 20, 25 $\mu\text{mol/L}$) standard sample was measured to obtain a standard curve. The concentrations of AA and HMF formation in reaction solution were calculated by the standard curve.

Statistical analysis

All analyses were carried out at least in triplicate and the results are expressed as the mean value $\pm$ standard deviation. Statistical analysis was performed using SPSS 19 software (Chicago, USA). Significant differences were calculated by ANOVA test, and the results with $p < 0.05$ were considered to be statistically significant.

Results and discussion

Sodium glutamate was successfully encapsulated using the spray drying bed coating method described above. Figure 1a shows the surface morphology of the sodium glutamate microcapsules. Microcapsules with a mean diameter of $71.57 \pm 0.41 \mu\text{m}$ (Fig. 1c) were obtained with carnauba wax (CarW) coatings. The surface roughness of the microcapsules is highlighted by the magnified SEM images

(cf. Fig. 1b). Conductimetry can be used to evaluate the barrier ability of the CarW coating and to isolate sodium glutamate from the external environment. The microcapsules were dispersed in water and the release of sodium glutamate was monitored over time by plotting the increase of water conductivity. Figure 1d indicates that microcapsules coated by CarW may lower the release rate of sodium glutamate.

The concentration effects of sodium glutamate/sodium glutamate microcapsules on the formation of AA in an asparagine–glucose model system during heating at 165 $^{\circ}\text{C}$ for 35 min are shown in Fig. 2a. The data clearly show that the AA inhibition efficiency by addition of sodium glutamate microcapsules is significantly ($p < 0.01$) better than that observed for free sodium glutamate at varying concentrations. In particular, the aqueous model system with 0.408 $\mu\text{g/g}$ of sodium glutamate showed the lowest AA concentration of $3.577 \pm 0.2 \mu\text{mol}$, whereas sodium glutamate microcapsules containing the same sodium glutamate addition showed the lowest AA concentration of $2.895 \pm 0.151 \mu\text{mol}$. As a result, the inhibition efficiency was determined to be increased by 19.07%. This latter finding can be explained by the improved permeability characteristics of sodium ions compared to glutamic acid ions within the microcapsules.

As shows in Fig. 2b, a considerable difference on the HMF formation could be determined between the sodium glutamate and sodium glutamate microcapsules during heating at 165 $^{\circ}\text{C}$ for 35 min. Free sodium glutamate can promote the formation of HMF in model systems due to the fact that sodium ions exhibited a Lewis acid behavior in the model systems that may accelerate the dehydration of glucose to form HMF (Tyrlik et al. 1999). On the contrary, sodium glutamate microcapsules displayed no promotion effect, a slight inhibition effect could be observed. For example, a highest HMF concentration of $9.131 \pm 0.216 \mu\text{mol}$ formed in the model system with 0.306 $\mu\text{g/g}$ of sodium glutamate was found, whereas sodium glutamate microcapsules containing the same amount of sodium glutamate only formed $1.432 \pm 0.150 \mu\text{g/g}$ HMF. The inhibition efficiency was found to increase by 84.32%. This result suggested that subtracting the agent catalyzing the HMF formation was an effective mitigation strategy, which proved to be in good agreement with previously published reports (Combs et al. 2013). Therefore, it can be determined that sodium glutamate microcapsules can indeed lower the release of sodium ions in an asparagine–glucose model system.

The time course for the formation of AA and HMF in the asparagine–glucose model system is shown in Table 1. The data in Table 1 suggest that the concentration of AA slowly increases during the first 25 min in all experimental and control groups. The AA concentration rapidly

Fig. 1 **a** SEM images of the sodium glutamate microcapsules. **b** Magnified SEM images of a single sodium glutamate microcapsule. **c** Statistical size distribution of sodium glutamate microcapsules. **d** Sodium glutamate cumulative release profiles in water (standard deviation obtained via triplicate analysis): free sodium glutamate (*rectangle*), sodium glutamate coated with carnauba wax (*circle*)

Fig. 2 Effect of free sodium glutamate (*circle*) and sodium glutamate microcapsules (*triangle*) at varying concentration on the formation of AA (**a**) and HMF (**b**) in the asparagine–glucose model system after

heating at 165 °C for 35 min. *Notes* The concentration for the sodium glutamate microcapsules group means the concentration of free sodium glutamate contained in microcapsules

increases, particularly in the control group (i.e. water), containing an AA concentration ranging from 0.56 ± 0.07 to 4.47 ± 0.36 μmol. Although the sodium glutamate group and the microcapsules group also exhibit a rapid increase of AA, the overall AA concentration is found to be less than the AA concentration in the control group at all time points. Compared to the sodium glutamate group, the microcapsules group displays a significantly increased inhibition efficiency, particularly in 30, 35, 40 min ($p < 0.05$). For instance, the relative inhibition efficiency

reaches 60.35% adding sodium glutamate microcapsules during heating for 40 min at 165 °C, whereas an inhibition efficiency of 44.06% could be observed in the sodium glutamate group. Moreover, the inhibition efficiency significantly increased from 6.75 to 60.35% with increasing the reaction time from 25 to 40 min, suggesting that the strategy involving microcapsules proves to be far superior at prolonged heating times.

Table 2 shows that the formation of HMF slowly increases in the first 15 min, followed by a rapid increase.

Table 1 Effect of heating time on AA formation with addition water, sodium glutamate and sodium glutamate microcapsules during heating at 165 °C

Time (min)	Water	Sodium glutamate	Sodium glutamate microcapsules
	AA (μmol)	AA (μmol)	AA (μmol)
10	0.11 ± 0.02 ^a	0.05 ± 0.01 ^a	Not detected
15	0.31 ± 0.05 ^a	0.13 ± 0.02 ^b	0.10 ± 0.04 ^b
20	0.44 ± 0.13 ^a	0.40 ± 0.05 ^a	0.27 ± 0.08 ^b
25	0.56 ± 0.07 ^a	0.58 ± 0.13 ^a	0.52 ± 0.08 ^a
30	1.90 ± 0.14 ^a	1.74 ± 0.23 ^a	1.51 ± 0.09 ^b
35	4.33 ± 0.11 ^a	3.58 ± 0.22 ^b	2.90 ± 0.15 ^c
40	4.47 ± 0.36 ^a	2.50 ± 0.26 ^b	1.77 ± 0.18 ^c

200 μL neat water was used as control group in model system

^{a–c} Different letters indicate a significant difference ($p < 0.05$) within each row**Table 2** Effect of heating time on HMF formation with addition water, sodium glutamate and sodium glutamate microcapsules during heating at 165 °C

Time (min)	Water	Sodium glutamate	Sodium glutamate microcapsules
	HMF(μmol)	HMF (μmol)	HMF (μmol)
10	0.05 ± 0.01 ^a	0.09 ± 0.01 ^a	Not detected
15	0.12 ± 0.02 ^a	0.27 ± 0.05 ^b	0.11 ± 0.01 ^a
20	1.20 ± 0.12 ^a	1.19 ± 0.08 ^a	1.3 ± 0.13 ^a
25	4.29 ± 0.21 ^a	4.47 ± 0.36 ^a	4.03 ± 0.36 ^a
30	5.44 ± 0.24 ^a	6.60 ± 0.20 ^b	3.68 ± 0.33 ^c
35	2.30 ± 0.20 ^a	8.57 ± 0.15 ^b	1.38 ± 0.11 ^c
40	1.14 ± 0.16 ^a	2.28 ± 0.14 ^b	0.23 ± 0.02 ^c

200 μL neat water was used as control group in model system

^{a–c} Different letters indicate a significant difference ($p < 0.05$) within each row

With prolonged reaction times, however, the HMF formation decreases. The results obtained suggest that HMF proves to be unstable during heating with various degradation reactions taking place to form furfural through demethylation. Consistent with the observations described above, the sodium ions promote the formation of HMF at all heating times due to dehydration of glucose accelerated by sodium ions acting as Lewis acid. However, the sodium glutamate microcapsules do not promote but inhibit the HMF formation. A maximum HMF concentration of 8.57 ± 0.15 μmol formed in sodium glutamate group upon heating for 35 min could be determined, with a promotion efficiency found to be 271.88%. The HMF concentration in the sodium glutamate microcapsules group was found to be 1.381 ± 1.08 μmol, with a corresponding inhibition efficiency of 40.07%. Even more surprisingly, the inhibition efficiency for HMF increases from 5.98 to 79.72%, while increasing the reaction time from 25 to 40 min. The latter finding suggests that a prolonged heating time in turn results in a significantly increased inhibition efficiency, because there was significant difference ($p < 0.05$) among water, sodium glutamate and sodium glutamate microcapsules groups for heating above 25 min. This result clearly

indicates that the addition of sodium glutamate microcapsules during food heating processes may provide a powerful technique to inhibit the formation of AA and HMF.

Fiore et al. (2012) work relating to the encapsulation of NaCl can be used to prevent the formation of HMF, but they did not describe the inhibition efficiency for AA. While the presence of sodium glutamate microcapsules in our work significantly inhibited AA formation ($p < 0.05$), compared to adding free sodium glutamate. Metal ions are usually utilized to inhibition the formation of AA (Açar et al. 2012; Kalita and Jayanty 2013; Van der Fels-Klerx et al. 2014), while the microcapsules can lower the release rate of metal cations ions. In this situation, there is negative factor for inhibition of AA formation. Therefore, our future work should focus on implementing how the anion ions effect the AA formation, especially containing glutamate acids ions, so that we can further confirm the inhibition mechanism using sodium glutamate microcapsules.

To date, yeast fermentation is only reported method for simultaneous inhibition of acrylamide and Hydroxymethylfurfural (Akillioglu and Gökmen 2014). The maximum inhibition efficiency for AA and HMF were 70 and 99.2% in instant coffee mixed with 10% sucrose,

respectively. This results seem to exceed our results (19.07% for AA, 84.2% for HMF). The reason may be explained by Nguyen et al. (2016), because the glucose is more conducive to form AA and HMF in biscuits, compared to adding sucrose in biscuits.

Conclusion

A new strategy to simultaneously inhibit the formation of AA and HMF in an asparagine–glucose aqueous model system has been developed. This could be achieved by addition of sodium glutamate microcapsules. The maximum inhibition efficiency for AA and HMF increased by 19.07 and 84.32%, respectively. And increasing the reaction time from 25 to 40 min, the inhibition efficiency for AA and HMF increased from 6.75 to 60.35% and 5.98 to 79.72%, respectively. The finding indicated that prolonged heating time can significantly increase the inhibition efficacy. Further investigations are currently underway to expand our studies to the inhibition effects demonstrated by sodium glutamate microcapsules in thermally treated actual foods.

Acknowledgements The authors are grateful to the Natural Science Foundation of China (NSFC, 31301484), the Natural Science Foundation of Hunan Province (2015JJ3082) and the Youth Foundation of Hunan Agricultural University (14QNZ14, 14QN11).

References

- Açar ÖÇ, Pollio M, Di Monaco R, Fogliano V, Gökmen V (2012) Effect of calcium on acrylamide level and sensory properties of cookies. *Food Bioprocess Technol* 5(2):519–526
- Akillioglu HG, Gökmen V (2014) Mitigation of acrylamide and hydroxymethyl furfural in instant coffee by yeast fermentation. *Food Res Int* 61:252–256
- Besaratinia A, Pfeifer GP (2007) A review of mechanisms of acrylamide carcinogenicity. *Carcinogenesis* 28(3):519–528
- Capuano E, Fogliano V (2011) Acrylamide and 5-hydroxymethylfurfural (HMF): a review on metabolism, toxicity, occurrence in food and mitigation strategies. *LWT Food Sci Technol* 44(4):793–810
- Combs E, Cinlar B, Pagan-Torres Y, Dumesic JA, Shanks BH (2013) Influence of alkali and alkaline earth metal salts on glucose conversion to 5-hydroxymethylfurfural in an aqueous system. *Catal Commun* 30:1–4
- da Silva PT, Martins Fries LL, de Menezes CR, Holkem AT, Schwan CL, Wigmann EF, Bastos JDO, da Silva CDB (2014) Microencapsulation: concepts, mechanisms, methods and some applications in food technology. *Cienc Rural* 44(7):1304–1311
- Duda-Chodak A, Wajda Ł, Tarko T, Sroka P, Satora P (2016) A review of the interactions between acrylamide, microorganisms and food components. *Food Funct* 7:1282–1295
- Fiore A, Troise AD, Mogol BA, Roullier V, Gourdon A, Jian SEM, Hamzalioglu BA, Gökmen V, Fogliano V (2012) Controlling the Maillard reaction by reactant encapsulation: sodium chloride in cookies. *J Agric Food Chem* 60(43):10808–10814
- Friedman M, Levin CE (2008) Review of methods for the reduction of dietary content and toxicity of acrylamide. *J Agric Food Chem* 56(15):6113–6140
- Gökmen V, Senyuva HZ (2007) Effects of some cations on the formation of acrylamide and furfurals in glucose-asparagine model system. *Eur Food Res Technol* 225(5–6):815–820
- Hidalgo FJ, Delgado RM, Zamora R (2010) Role of mercaptans on acrylamide elimination. *Food Chem* 122(3):596–601
- Hogervorst JGF, Baars BJ, Schouten LJ, Konings EJM, Goldbohm RA, van den Brandt PA (2010) The carcinogenicity of dietary acrylamide intake: a comparative discussion of epidemiological and experimental animal research. *Crit Rev Toxicol* 40(6):485–512
- IARC (1994) Acrylamide. In: IARC monographs on the evaluation of carcinogen risk to humans some industrial chemicals. International Agency for Research on Cancer, Lyon, pp 389–433
- Kalita D, Jayanty SS (2013) Reduction of acrylamide formation by vanadium salt in potato French fries and chips. *Food Chem* 138(1):644–649
- Liu J, Chen F, Man Y, Dong L, Hu X (2011) The pathways for the removal of acrylamide in model systems using glycine based on the identification of reaction products. *Food Chem* 128(2):442–449
- Miao YT, Zhang HJ, Zhang LL, Wu SJ, Sun YJ, Shan Y, Yuan Y (2014) Acrylamide and 5-hydroxymethylfurfural formation in reconstituted potato chips during frying. *J Food Sci Technol* 51(12):4005–4011
- Michalak J, Gujska E, Czarnowska M, Klepacka J, Nowak F (2016) Effect of storage on acrylamide and 5-hydroxymethylfurfural contents in selected processed plant products with long shelf-life. *Plant Foods Hum Nutr* 71:115–122
- Nguyen HT, Van der Fels-Klerx HJ, Peters RJB, Van Boekel MAJS (2016) Acrylamide and 5-hydroxymethylfurfural formation during baking of biscuits: part I: Effects of sugar type. *Food Chem* 192:575–585
- Riboldi BP, Vinhas AM, Moreira JD (2014) Risks of dietary acrylamide exposure: a systematic review. *Food Chem* 157:310–322
- Shin DC, Kim CT, Lee YC, Choi WJ, Na YJ, Lee KW (2010) Reduction of acrylamide by taurine in aqueous and potato chip model systems. *Food Res Int* 43(5):1356–1360
- Troise AD, Fogliano V (2013) Reactants encapsulation and Maillard reaction. *Trends Food Sci Tech* 33(1):63–74
- Tyrlik SK, Szerszen D, Olejnik M, Danikiewicz W (1999) Selective dehydration of glucose to hydroxymethylfurfural and a one-pot synthesis of a 4-acetylbutyrolactone from glucose and trioxane in solutions of aluminium salts. *Carbohydr Res* 315(3–4):268–272
- Van der Fels-Klerx HJ, Capuano E, Nguyen HT, Mogol BA, Kocadagli T, Tas NG, Hamzalioglu A, Van Boekel MAJS, Gökmen V (2014) Acrylamide and 5-hydroxymethylfurfural formation during baking of biscuits: NaCl and temperature-time profile effects and kinetics. *Food Res Int* 57:210–217
- Xu Y, Cui B, Ran R, Liu Y, Chen H, Kai G, Shi J (2014) Risk assessment, formation, and mitigation of dietary acrylamide: current status and future prospects. *Food Chem Toxicol* 69:1–12
- Zhu YC, Wang PP, Wang F, Zhao MY, Hu XS, Chen F (2016) The kinetics of the inhibition of acrylamide by glycine in potato model systems. *J Sci Food Agric* 96:548–554