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25 **Abstract**

26 The inhibitory effect of three polysaccharides (alginate, pectin and chitosan) on acrylamide
27 formation was investigated in a chemical and a fried potato chip food system, under two
28 heating regimes (heating block and microwave). In the chemical system, acrylamide formation
29 followed a second order reaction kinetic behaviour. Activation energies (E_a) were 17.85 and
30 110.78 kJ/mol for conventional and microwave heating respectively. Acrylamide content was
31 highest at 180°C after 60 min conventional heating (27.88 ng/ml) and 3.5 fold higher after
32 microwave heating for 60 s (800W, 98.02 ng/ml). Alginate (0.3% w/v) and pectin (0.2% w/v)
33 solutions efficiently inhibited acrylamide formation by 65% and 56% respectively under
34 conventional heating, and 36% and 30% respectively under microwave heating. Coating
35 potatoes with alginate, pectin and chitosan (1% w/v) prior to frying dramatically inhibited
36 acrylamide formation by 54%, 51% and 41% respectively. However only alginate and pectin
37 slightly reduced acrylamide by 5% in the microwave.

38

39 **Keywords:** Acrylamide; microwave; polysaccharides; pectin; alginate; chitosan; Maillard;
40 potato

41 **Chemical compounds:**

42 Acrylamide (PubChem CID: 6579); Pectin (PubChem CID: 441476); Alginic acid (PubChem CID:
43 6850754); Chitosan (PubChem CID: 71853); Asparagine (PubChem CID: 6267).

44

45 **1. Introduction**

46 Acrylamide is classified as a group 2A carcinogen (probably carcinogenic to humans) by the
47 International Agency for Research on Cancer (IARC, 1994). Acrylamide is not naturally present
48 in foods, but can be formed during thermal food processing. Acrylamide is detected in heat
49 processed starchy foods such as potato chips and fries, bakery products and roasted coffee
50 (Krishnakumar and Visvanathan, 2014). The major pathway for acrylamide formation is the
51 Maillard reaction between the α -amino group of free asparagine and carbonyl group of a
52 reducing sugar (Mottram et al., 2002). A minor route is from the degradation of acrolein (Gertz
53 and Klostermann, 2002). Mass spectral studies have shown that the three carbon atoms and
54 the nitrogen atom of acrylamide are all derived from asparagine (Zyzak et al., 2003).

55 Acrylamide formation is affected by many factors, such as the concentration and ratio of
56 precursors (i.e. asparagine and reducing sugar), pH, water content, water activity, and physical
57 process parameters such as heating time and temperature (Anese et al., 2009). The interaction
58 between heating temperature and heating time was shown to be an important factor for
59 acrylamide formation (Taubert et al., 2004). Most studies use heated surfaces to heat the
60 material, which is mostly heat transfer by conduction from the hot surface to the heating vessel
61 and subsequent convection within the material, particularly for liquids. Microwave heating is
62 widely used in domestic and commercial food heating operations. Contradictory and non-
63 conclusive results have been reported on the impact of microwave heating on acrylamide
64 formation (Michalak et al., 2020). Recent studies indicated that microwave heating facilitates
65 the Maillard reaction in a similar way to conventional heating such as boiling or frying (Maskan,
66 2001, Oliveira and Franca, 2002), and have shown acrylamide formation (Yuan et al., 2007,
67 Zhang et al., 2008b). Other studies reported that acrylamide is not typically found in boiled or
68 microwaved foods (Capuano and Fogliano, 2011, Krishnakumar and Visvanathan, 2014). The

69 contradictory results on acrylamide formation during microwave heating led to the conclusion
70 that it may be difficult to control temperature during the experiment.

71 Although there is no set maximum limit for acrylamide content in foods, it is generally accepted
72 that acrylamide levels in foods should be minimized as much as possible (Dybing et al., 2005).
73 In order to reduce acrylamide formation during cooking, inhibitors may be used. Hydrocolloids
74 such as pectin, alginic acid and xanthan gum were reported to significantly inhibit acrylamide
75 formation during cooking (Zeng et al., 2010). Coating with hydrocolloid could reduce oil uptake
76 and modify the heating properties of the food system during frying, with no apparent negative
77 effects on sensory attributes (Kurek et al., 2017, Zeng et al., 2010).

78 The aim of this study is to investigate the inhibitory effect of three polysaccharides (citrus
79 pectin, sodium alginate and chitosan) tested at various concentrations, on acrylamide
80 formation in chemical and food model systems. In both systems, a comparative effect of
81 different processing methods (conventional heating in a heating block and microwave heating)
82 on the formation of acrylamide were examined under controlled temperature and time
83 conditions. In contrast to previous research, we used a Microwave Accelerated Reaction
84 System to carefully monitor temperature changes in model system in the microwave.

85 The hypothesis tested was: polysaccharides inhibit acrylamide formation in both chemical and
86 food models under heating block and microwave heating.

87 **2. Materials and methods**

88 **2.1 Acrylamide formation in chemical model system**

89 a) Conventional heating

90 The reaction under conventional heating was carried out following the method described by
91 Sansano et al. (2017) with minor modifications. In this study heating block was used to generate

92 heat instead of oil bath due to constant temperature. The mixture between asparagine (Fisher,
93 AC371601000) and glucose (Sigma-Aldrich, G8644) was heated at equimolar amounts; 5 μ M
94 glucose and 5 μ M asparagine (1.5 mL of each) were mixed in a Pyrex tube fitted with a screw cap.
95 Samples were heated at 150, 160, 170 and 180°C in heating block (VWR analog Heatblock,
96 Hampton, NH, USA) for 10, 20, 30, 40, 50 and 60 min. Heating block was pre-heated for 2 hours.
97 The temperature fluctuation was within 2°C. The tubes were occasionally swirled manually. The
98 heating block temperature was measured using an infrared thermometer. It was assumed that
99 temperature in the heating block was identical to the temperature inside the tube by neglecting
100 the conductive resistance to heat transfer. At the end of the heating time, the samples were
101 cooled immediately in an ice bath to stop reaction for 5 min.

102 b) Microwave heating

103 The microwave heating was performed via a Microwave Accelerated Reaction System (Model
104 MARS 6[®], Matthews, NC, USA). In the microwave chamber, there were 10 microwave sample
105 vessels in a rotating carousel, which allowed 10 simultaneous sample reactions under identical
106 reaction conditions. The reaction temperature, time, and the control limits were modulated via
107 a digital intelligent control panel. The reaction mixtures were treated at the constant microwave
108 power of 800W with even wave administration (no hotspots). All reactions contained the same
109 reactant concentrations as described for the conventional heating reactions and microwaved for
110 30, 60, 90 and 120 sec. The mixtures were then cooled immediately in an ice bath.

111 **2.2 Acrylamide formation in food model system**

112 a) Fried potato chips

113 A batch of potatoes (variety Maris Piper) was purchased from local market. Potatoes were
114 washed, peeled and cut into the similar size strips (10 x 10 x 50 mm) prior to frying in a pre-
115 heated deep fat fryer (Cookworks™) in sunflower oil at 170 °C for 3 min. Samples were cooled

116 and drained of excess oil on a metal sieve. Fried potato chips were ground using mini food
117 processor.

118 Acrylamide extraction from food model was adapted from Gökmen and Şenyuva (2007). Ground
119 food sample (1 g) was weighted into a 15 ml centrifuge tube. Carrez I and II (500 µL of each) and
120 9 ml of 1.2% (v/v) of acetic acid were added. Sample was mixed vigorously for 2 min. After mixing,
121 1ml of sample was centrifuged at 10,000 rpm for 10 min at 0°C (Centrifuge 5424R Eppendorf).
122 Supernatant was collected and diluted with Milli-Q water (1:10) before HPLC analysis.

123 b) Microwaved potato chips

124 Potatoes were washed, peeled and cut into the similar size strips (10 x 10 x 50 mm) prior to
125 heating in commercial microwave. Our preliminary experiment showed that at 3 min potato
126 chips did not form any brown color, and 5 min would burn the potato chips. Therefore,
127 microwave process was performed at 800 W for 4 min. All samples were cooled before grinding
128 in mini food processor and extracted as previously described.

129 **2.3 Kinetic calculation**

130 The order of reaction and the reaction rate constant (k) for the formation of acrylamide were
131 calculated from linear regression of the concentration and 1/concentration versus reaction time
132 for zero, first and second order reaction kinetics, respectively. When linear graph was obtained,
133 the natural logarithm of rate constant (k) was plotted versus $1/T$ (K unit) to calculate activation
134 energy (E_a) using Arrhenius equation ($\ln k = \ln k_0 - E_a/RT$).

135 **2.4 UV-Vis spectrophotometer measurement**

136 A UV–VIS spectrophotometer (SPECORD 210 PLUS, Analytik, Jena, Germany) was used to monitor
137 the reaction according to Zhou et al. (2016). Samples were diluted in water (1:50) and the
138 absorbance was measured at 294 and 420 nm to determine the intermediate and final products
139 of Maillard reaction, respectively.

140 **2.5 Acrylamide determination by HPLC**

141 Acrylamide was analyzed in triplicate following the method by Galani et al. (2017) with slight
142 modifications. A HPLC system (Agilent 1200 series, Santa Clara, CA, USA) equipped with an auto
143 sampler and a diode array detector was used. Two microliters of sample were injected by auto
144 sampler and separated using a Zorbax 300 Extend C18 analytical column (2.1 mm x 100 mm, 3.5
145 μm) (Santa Clara, California, USA). Formic acid (Sigma-Aldrich, F0507) (0.1% in water) was used
146 as mobile phase with flow rate of 0.1 mL/min. The running time was 5 min and retention time of
147 acrylamide was at 3.4 min. Acrylamide solution (Sigma-Aldrich, A9099) (1 mg/mL) was prepared,
148 then a series of acrylamide concentrations (1 to 100 $\mu\text{g/mL}$) were prepared from the stock
149 solution. The position of the acrylamide peak in reaction mixtures was confirmed by spiking. All
150 test samples were diluted in Milli-Q water to be within the standard range and filtered with Nylon
151 filter (0.45 μm) (Sigma-Aldrich Co., St. Louis, MO, USA) and transferred to a vial for
152 chromatography analysis.

153 **2.6 Preparation of polysaccharide solutions**

154 In chemical system, sodium alginate (Sigma-Aldrich, W201502) was dispersed in Milli Q water
155 (1g in 100 ml) and heated at 70°C with stirring for 30 min, then cooled down at ambient
156 temperature. Dilutions were made to 0.1% to 0.3% (v/v) (pH=4). Pectin from citrus peel (Sigma-
157 Aldrich, P9135) was dispersed in Milli Q water (1g in 100 ml) and stirred overnight at room
158 temperature. Pectin solutions were diluted to 0.1% to 0.3% (v/v) (pH=4). 1g of chitosan (Sigma-
159 Aldrich, 448869) which had molecular weight at 50-190 kDa and 75-85% deacetylated degree
160 was solubilized in acetic acid (1% v/v), 100 ml and stirred overnight until completely dissolve.
161 Dilutions were made to 0.1% to 0.3% (v/v) with 1% acetic acid and adjusted pH to 4.0 by 0.1M
162 and 1M NaOH.

163 In food system, 1% dilution of sodium alginate, pectin and chitosan were made using same
164 method as describe above. Potatoes (50 g per portion) were soaked in inhibitor solution (50 ml)
165 for 30 min and drained for 2 min before frying.

166 2.7 Statistical analysis

167 The data was subjected to analysis of variance (ANOVA) and least significance difference test to
168 determine difference between means. Duncan's multiple range tests was used to compare
169 means at a significance level of 0.05 using the SPSS software package version 24 (IBM Institute.,
170 New York, USA).

171 3. Result and discussion

172 3.1 Inhibitory effect of polysaccharides on acrylamide formation in a chemical model system

173 3.1.1 Acrylamide formation in chemical model system

174 Conventional heating in a heating block resulted in acrylamide formation under all temperature
175 conditions, with the highest levels recorded at 180 °C after 60 min of heating (27.88 µg/mL) (

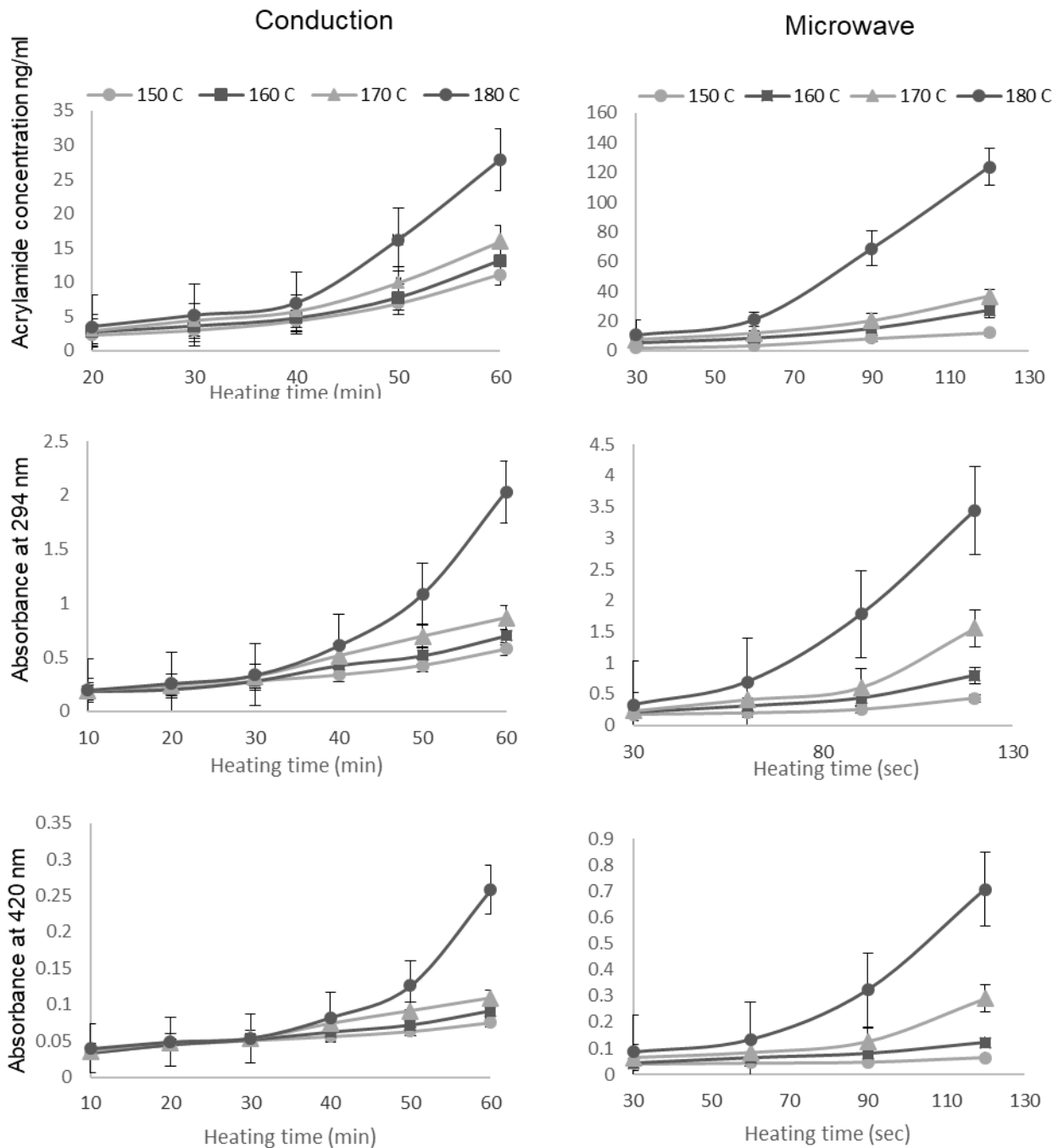
176 The formation of Maillard reaction intermediates was monitored with UV–Vis spectrometry at
177 294 nm and 420 nm (Figure 1). Absorbance values at 294 nm increased steadily with time at 150,
178 160 and 170°C, with a much steeper increase in absorbance values at 180°C after 40 min. These
179 values correlate with acrylamide content in those conditions. Much smaller changes in
180 absorbance values at 420 nm were observed, suggesting that 294 nm is a better wavelength to
181 monitor the reaction. Microwave heating showed similar patterns of absorbance change.

182 1). There was a marked increase in the rate of formation after 40 min of heating at 180°C.
183 Gökmen and Şenyuva (2007) reported that high levels of acrylamide were generated at elevated
184 heating temperature (180°C) and heating time (10 min), and decreased slightly after 10min until
185 60min, likely due to degradation of acrylamide into other compounds. This decrease was not
186 observed in this study.

187 When the same reaction mixtures were subjected to microwave heating at a power of 800W,
188 the results also showed an increase in acrylamide with increased temperature and time (Figure
189 1). There was a similar pattern of acrylamide formation between conventional and microwave
190 heating, however it must be noted that the timescale in the microwave experiment is in seconds,
191 while the timescale in the conventional heating system is in minutes. It is important to note that
192 the microwave reactor is designed to prevent hotspots, and therefore we are confident that
193 acrylamide formation was uniform in the solution.

194 Microwaves cause fast temperature rises in the solvent due to their capacity to generate heat
195 energy inside the system, without requiring any medium as vehicle for heat transfer. A low
196 thermal conductivity product may quickly reach high temperatures (Campañone and Zaritzky,
197 2005). Moreover, microwaves causes molecular friction in alternating electrical and magnetic
198 fields, resulting in dipolar rotation of polar molecule (such as water) and rapid heat generation
199 (Campañone and Zaritzky, 2005, Mudgett, 1989, Orzáez Villanueva et al., 2000).

200 The formation of Maillard reaction intermediates was monitored with UV–Vis spectrometry at
201 294 nm and 420 nm (Figure 1). Absorbance values at 294 nm increased steadily with time at 150,
202 160 and 170°C, with a much steeper increase in absorbance values at 180°C after 40 min. These
203 values correlate with acrylamide content in those conditions. Much smaller changes in
204 absorbance values at 420 nm were observed, suggesting that 294 nm is a better wavelength to
205 monitor the reaction. Microwave heating showed similar patterns of absorbance change.



206
 207 Figure 1. Acrylamide formation in the chemical model system during heating mainly by
 208 conduction in a heating block (conventional) and microwave at various temperatures. The
 209 absorbance of the solutions was measured at 294 and 420 nm.

210 **3.1.2 Kinetic parameters**

211 Acrylamide concentrations formed at different time-temperature combinations were used to
 212 calculate the kinetic parameters. The concentration of acrylamide formed at various heating

213 temperature was linear regressed against reaction time, and indicated that the reaction followed
 214 a second-order reaction. This means that the reaction rate depends on the square of the
 215 concentration of one or more reactants. This is consistent with previous observations by BeMiller
 216 (2019), but contrasts with the results from Gokmen and Senyuva (2006). They used a fructose-
 217 asparagine mixture to study acrylamide formation at 120-200°C. Their results show that the
 218 reaction followed zero order and first order with respect to asparagine and fructose,
 219 respectively. As the concentration of asparagine increased, the rate of reaction remained
 220 constant.

221 Activation energy (E_a) was calculated using the Arrhenius equation from rate constants at each
 222 temperature (

223 The formation of Maillard reaction intermediates was monitored with UV–Vis spectrometry at
 224 294 nm and 420 nm (Figure 1). Absorbance values at 294 nm increased steadily with time at 150,
 225 160 and 170°C, with a much steeper increase in absorbance values at 180°C after 40 min. These
 226 values correlate with acrylamide content in those conditions. Much smaller changes in
 227 absorbance values at 420 nm were observed, suggesting that 294 nm is a better wavelength to
 228 monitor the reaction. Microwave heating showed similar patterns of absorbance change.

229). The apparent activation energy (E_a) was 17.85 ($r^2 = 0.884$) and 110.78 ($r^2 = 0.829$) kJ/mol for
 230 conventional and microwave, respectively. This indicates that a higher E_a is needed in the
 231 microwave heating conditions, but once activation energy is reached, the reaction progresses
 232 rapidly.

233 Table 1. Kinetic parameters of acrylamide formation in the chemical model under different
 234 heating conditions.

T °C	Conduction heating		Microwave heating	
	k (s ⁻¹)	R ²	k (s ⁻¹)	R ²

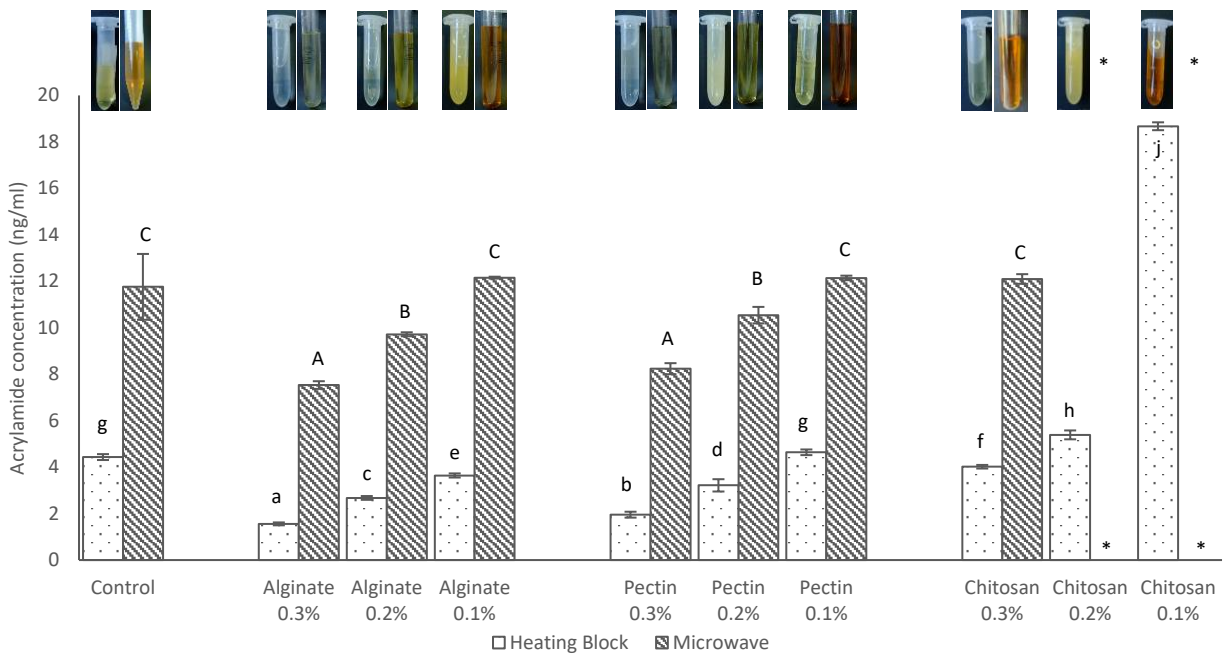
150	0.0302	0.9882	0.0204	0.92822
160	0.0385	0.9740	0.0180	0.9966
170	0.0421	0.9881	0.0176	0.9961
180	0.0529	0.9688	0.0151	0.9512

235

236 3.1.3. Inhibitory effect of polysaccharides on acrylamide formation

237 The inhibitory effect of sodium alginate, pectin and chitosan on acrylamide formation were
238 investigated. Figure 2 shows that sodium alginate and pectin at 0.3% and 0.2% w/v reduced
239 acrylamide formation significantly in both conventional and microwave heating conditions
240 compared to control. At a concentration of 0.3% w/v, alginate and pectin reduced acrylamide
241 formation by 64.9% and 55.9% respectively in conventional, and 35.9% and 30% respectively in
242 microwave. Zeng et al. (2010) showed similar results with inhibition >50% for pectin and alginic
243 acid in conventional heating conditions, but with much higher solution concentration (2% w/w).
244 However, very low concentration of alginate and pectin (0.1% w/v) did not show as good
245 inhibition effect as higher concentration (0.2 - 0.3% w/v). The mechanisms by which sodium
246 alginate inhibits acrylamide formation have been proposed in previous studies. Gökmen and
247 Şenyuva (2007) found that Na⁺ almost halved the acrylamide formation, because the cations
248 prevented the formation of key intermediates. Lindsay and Jang (2005) also suggested that ionic
249 associations involving the ions and charged groups on asparagine and related intermediates
250 were likely to be involved. Pectin effectively inhibited acrylamide by lowering the pH without
251 contributing to the reducing sugars content, and higher concentration of pectin (up to 5%) was
252 found to be more efficient in inhibiting acrylamide formation (Passos et al., 2018). Beside the
253 ionic and pH effects, the presence of long polysaccharide chains are likely to prevent substrates
254 coming together and slow down the motion of molecules in the chemical model system.

255 Chitosan did not inhibit acrylamide formation to the same extent as alginate and pectin. Only the
256 highest concentration (0.3%) used slightly reduced (9.46%) acrylamide formation (Figure 2). Sung
257 et al. (2018) found 1% chitosan reduced acrylamide formation by 46.8% and proposed that the
258 amino groups of chitosan could compete with asparagine and react with the carbonyl groups of
259 glucose in order to inhibit the formation of Maillard reaction products and acrylamide. Sansano
260 et al. (2017) found that adding 0.5% of chitosan led to an inhibition of acrylamide formation by
261 52%, while 1% of chitosan could inhibit for 75% at 180 °C. On the other hand, Figure 2 shows that
262 low concentration (0.2 and 0.1% w/v) of chitosan promoted acrylamide formation in
263 conventional heating, with 0.1 % chitosan increasing acrylamide by almost five-fold compare to
264 control. Samples containing low concentration of chitosan (0.2 and 0.1% w/v) carbonized in the
265 microwave, hence acrylamide content could not be determined, but suggesting the reaction was
266 taking place at a very high speed. Therefore, the concentration of chitosan is a critical factor to
267 determine whether it inhibits or promotes acrylamide formation. Previous studies also suggested
268 that different properties of chitosan would significantly influence its potential to inhibit
269 acrylamide formation, including molecular weight (Mw) (Chang et al., 2016) and deacetylation
270 degree (DD) (TSAI et al., 2002, Sansano et al., 2017). The chitosan used in this study had relatively
271 low Mw (50-190 kDa) and high DD (75-85%), both of these properties have been shown to be
272 associated with lower acrylamide formation (Sansano et al., 2017, Chang et al., 2016). However,
273 our study also shows chitosan concentration is critical to the inhibition effect.



275

276 Figure 2 Acrylamide formation in conventional heating and microwave in the chemical model in
 277 the presence of various inhibitors. The conventional heating was carried out at 170 °C for 30 min.
 278 The microwave reaction was carried out at 800W microwave power for 60s. Data values are
 279 means ± SD (n = 3). Different lowercase letters indicate significant difference at the 5% level for
 280 conventional heating, and uppercase letters for microwave. *Samples containing low
 281 concentration of chitosan (0.2 and 0.1% w/v) carbonized in the microwave, hence acrylamide
 282 content could not be determined.

283 **3.2 Inhibitory effect of polysaccharides on acrylamide formation in a food model (potato**
 284 **chips/fries)**

285 To investigate the effect of polysaccharide inhibitors on acrylamide formation in a food model,
 286 potatoes were deep-fried or microwaved after dipping in polysaccharide solutions. Figure 3
 287 shows the relative percentage of acrylamide in fried and microwave potatoes. Dipping in
 288 alginate, pectin and chitosan dramatically reduced acrylamide formation during frying by 53.5%,
 289 51.2% and 40.9% respectively compared to control frying. Microwave cooking potato chips

290 showed about a third less acrylamide formation compared to frying, and this was associated with
291 less browning at the surface. It must be noted that the crisps were cooked in a domestic
292 microwave, not the microwave reactor used in the food model. Domestic microwaves have less
293 homogeneous wave distribution, and it is therefore possible that hotspots were created within
294 the potato chip. However, our replicate analysis shows good reproducibility between samples,
295 indicating homogenous acrylamide formation. However for microwave cooking, only alginate
296 and pectin significantly reduced acrylamide formation and only by 5.2% for both polysaccharides.
297 Previous studies on the effect of microwave cooking on acrylamide formation have been
298 contradictory (Michalak et al., 2020). Some studies reported that microwave heating provides a
299 favorable medium for the occurrence of acrylamide and promote the acrylamide formation
300 (Michalak et al., 2017, Yuan et al., 2007, Zhang et al., 2008a), but other studies showed no
301 acrylamide formation under microwave heating (Anese et al., 2013, Barutcu et al., 2009). Others
302 suggest that microwave heating prior to frying may help to reduce acrylamide formation (Belgin
303 Erdoğan et al., 2007). The differences might be due to variations in microwave parameters such
304 as power or heating time, as well as the chemical composition and water activity levels (Michalak
305 et al., 2020).

306 Zeng et al. (2010) showed slightly different pattern for alginate and pectin in their food model
307 compare to the current study. They found that 1% w/w alginic acid only lead to about 20%
308 reduction of acrylamide, 1% pectin caused slightly elevated acrylamide contents and only
309 efficiently inhibited acrylamide after 5h immersion (Zeng et al., 2010). They suggest that duration
310 of immersion played a predominant role in determining the final effect of the treatment (Zeng
311 et al., 2010). Sansano et al. (2016) found low concentration of chitosan (0.27% w/v) mitigated
312 acrylamide formation by around 60% in batter system for frying, but did not inhibit when
313 concentration increased to 0.54% w/v. Our results shows all three polysaccharides at 1% w/w

314 efficiently reduced acrylamide formation, with alginate giving the best result followed by pectin
315 and chitosan.

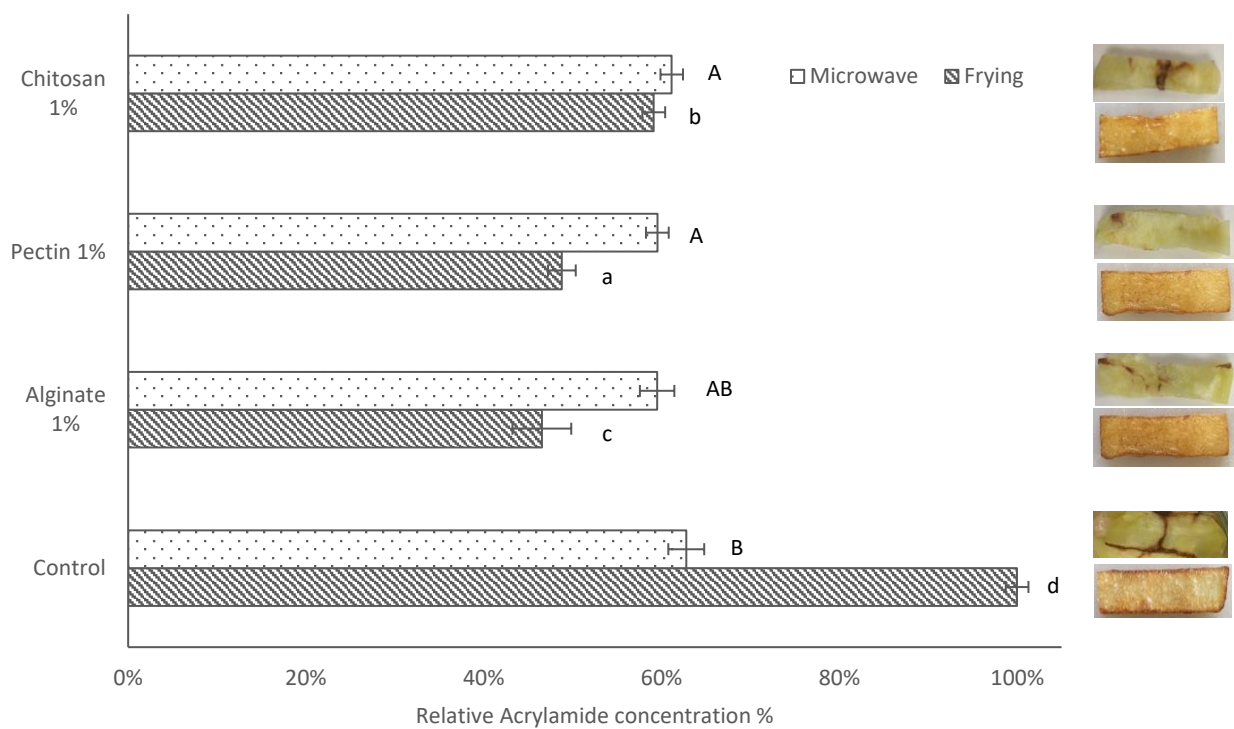
316 Gaonkar (1991) explained that immersion of hydrocolloid solution would lower the food surface
317 tension and thus facilitate the formation of a layer of coating on the surface of the food products.

318 Mousa (2018) confirmed that a rigid thermal gelation network formed during frying and prevent
319 interaction between acrylamide precursors. Zeng et al. (2010) and Suyatma et al. (2015) also

320 explained that pectin coating reduces heat penetration from the oil to the food during frying and
321 interact with acrylamide precursor. The mechanism of inhibition needs to be further studied to

322 confirm the role of hydrocolloids in influencing the acrylamide formation in food model systems.
323 The coatings did not seem to impact on colour formation or other aspects of appearance,

324 compared to control. However, the effect of the coatings on other sensory properties (flavour,
325 aroma) needs further investigation.



326

327 Figure 3. Acrylamide formation in the food model in the presence of various inhibitors relative
328 to control (frying with no inhibitors). The microwave cooking was carried out at 800W power for
329 4 min. Frying was carried out at 170°C for 3min. Data values are means \pm SD (n = 3). Different
330 lowercase letters indicate significant difference at 95% confidence level for frying, uppercase
331 letters for microwave compared to the control.

332 **4. Conclusion**

333 In this study, the inhibitory effect of polysaccharides on acrylamide formation was investigated
334 in chemical and food model systems under two heating modes (heating block and microwave).
335 Low concentration of polysaccharides (0.2 – 0.3% w/v) successfully inhibited acrylamide
336 formation in the chemical model, although chitosan was less effective compared to sodium
337 alginate and pectin. Low concentrations of chitosan (0.1%) increased acrylamide formation. In
338 the food system, the three polysaccharides (1% w/v) reduced acrylamide by up to 53.5% during
339 frying. However the inhibition was much lower when the chips were microwaved (only 5.2%).
340 Alginate was shown to be the most effective inhibitor of acrylamide formation in both chemical
341 and food model, followed by pectin, although the mechanism behind the inhibition needs to be
342 further investigated. Dipping in polysaccharide solution prior to frying is a promising acrylamide
343 mitigation strategy.

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347 The authors declare no conflicts of interest.

348 **6. References**

349 ANESE, M., MANZOCCO, L., CALLIGARIS, S. & NICOLI, M. C. 2013. Industrially Applicable Strategies for
350 Mitigating Acrylamide, Furan, and 5-Hydroxymethylfurfural in Food. *Journal of Agricultural and*
351 *Food Chemistry*, 61, 10209-10214.

352 ANESE, M., SUMAN, M. & NICOLI, M. C. 2009. Technological Strategies to Reduce Acrylamide Levels in
353 Heated Foods. *Food Engineering Reviews*, 1, 169-179.

354 BARUTCU, I., SAHIN, S. & SUMNU, G. 2009. Acrylamide formation in different batter formulations during
355 microwave frying. *LWT - Food Science and Technology*, 42, 17-22.

356 BELGIN ERDOĞDU, S., PALAZOĞLU, T. K., GÖKMEN, V., ŞENYUVA, H. Z. & EKIZ, H. İ. 2007. Reduction of
357 acrylamide formation in French fries by microwave pre-cooking of potato strips. 87, 133-137.

358 BEMILLER, J. N. 2019. 18 - Nonenzymic Browning and Formation of Acrylamide and Caramel. In:
359 BEMILLER, J. N. (ed.) *Carbohydrate Chemistry for Food Scientists (Third Edition)*. AACC
360 International Press.

361 CAMPAÑONE, L. A. & ZARITZKY, N. E. 2005. Mathematical analysis of microwave heating process.
362 *Journal of Food Engineering*, 69, 359-368.

363 CAPUANO, E. & FOGLIANO, V. 2011. Acrylamide and 5-hydroxymethylfurfural (HMF): A review on
364 metabolism, toxicity, occurrence in food and mitigation strategies. *LWT - Food Science and
365 Technology*, 44, 793-810.

366 CHANG, Y.-W., SUNG, W.-C. & CHEN, J.-Y. 2016. Effect of different molecular weight chitosans on the
367 mitigation of acrylamide formation and the functional properties of the resultant Maillard
368 reaction products. *Food Chemistry*, 199, 581-589.

369 DYBING, E., FARMER, P. B., ANDERSEN, M., FENNEL, T. R., LALLJIE, S. P. D., MÜLLER, D. J. G., OLIN, S.,
370 PETERSEN, B. J., SCHLATTER, J., SCHOLZ, G., SCIMECA, J. A., SLIMANI, N., TÖRNQVIST, M.,
371 TUIJTELAARS, S. & VERGER, P. 2005. Human exposure and internal dose assessments of
372 acrylamide in food. *Food and Chemical Toxicology*, 43, 365-410.

373 GALANI, J. H. Y., PATEL, N. J. & TALATI, J. G. 2017. Acrylamide-forming potential of cereals, legumes and
374 roots and tubers analyzed by UPLC-UV. *Food Chem Toxicol*, 108, 244-248.

375 GAONKAR, A. G. 1991. Surface and interfacial activities and emulsion characteristics of some food
376 hydrocolloids. *Food Hydrocolloids*, 5, 329-337.

377 GERTZ, C. & KLOSTERMANN, S. 2002. Analysis of acrylamide and mechanisms of its formation in deep-
378 fried products. 104, 762-771.

379 GOKMEN, V. & SENYUVA, H. Z. 2006. A simplified approach for the kinetic characterization of acrylamide
380 formation in fructose-asparagine model system. *Food Addit Contam*, 23, 348-54.

381 GÖKMEN, V. & ŞENYUVA, H. Z. 2007. Acrylamide formation is prevented by divalent cations during the
382 Maillard reaction. *Food Chemistry*, 103, 196-203.

383 IARC 1994. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 60. *Some
384 Industrial Chemicals*. World Health Organization.

385 KRISHNAKUMAR, T. & VISVANATHAN, R. 2014. Acrylamide in Food Products: A Review. *Journal of Food
386 Processing & Technology*, 05, 5-7.

387 KUREK, M., ŠČETAR, M. & GALIĆ, K. 2017. Edible coatings minimize fat uptake in deep fat fried products:
388 A review. *Food Hydrocolloids*, 71, 225-235.

389 LINDSAY, R. C. & JANG, S. Chemical Intervention Strategies for Substantial Suppression of Acrylamide
390 Formation in Fried Potato Products. In: FRIEDMAN, M. & MOTTRAM, D., eds. *Chemistry and
391 Safety of Acrylamide in Food, 2005// 2005 Boston, MA*. Springer US, 393-404.

392 MASKAN, M. 2001. Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal
393 of Food Engineering*, 48, 169-175.

394 MICHALAK, J., CZARNOWSKA-KUJAWSKA, M., KLEPACKA, J. & GUJSKA, E. 2020. Effect of Microwave
395 Heating on the Acrylamide Formation in Foods. 25, 4140.

396 MICHALAK, J., GUJSKA, E., CZARNOWSKA-KUJAWSKA, M. & NOWAK, F. 2017. Effect of different home-
397 cooking methods on acrylamide formation in pre-prepared croquettes. *Journal of Food
398 Composition and Analysis*, 56, 134-139.

399 MOTTRAM, D. S., WEDZICHA, B. L. & DODSON, A. T. 2002. Acrylamide is formed in the Maillard reaction.
400 *Nature*, 419, 448-449.

401 MOUSA, R. M. A. 2018. Simultaneous inhibition of acrylamide and oil uptake in deep fat fried potato
402 strips using gum Arabic-based coating incorporated with antioxidants extracted from spices.
403 *Food Hydrocolloids*, 83, 265-274.

404 MUDGETT, R. E. 1989. Microwave food processing. *AGRICULTURAL SCIENCE AND TECHNOLOGY*
405 *INFORMATION*, 43, 117.

406 OLIVEIRA, M. E. C. & FRANCA, A. S. 2002. Microwave heating of foodstuffs. *Journal of Food Engineering*,
407 53, 347-359.

408 ORZÁEZ VILLANUEVA, M. T., DÍAZ MARQUINA, A., FRANCO VARGAS, E. & BLÁZQUEZ ABELLÁN, G. 2000.
409 Modification of vitamins B1 and B2 by culinary processes: traditional systems and microwaves.
410 *Food Chemistry*, 71, 417-421.

411 PASSOS, C. P., FERREIRA, S. S., SERÔDIO, A., BASIL, E., MARKOVÁ, L., KUKUROVÁ, K., CIESAROVÁ, Z. &
412 COIMBRA, M. A. 2018. Pectic polysaccharides as an acrylamide mitigation strategy
413 – Competition between reducing sugars and sugar acids. *Food Hydrocolloids*, 81, 113-119.

414 SANSANO, M., CASTELLÓ, M. L., HEREDIA, A. & ANDRÉS, A. 2016. Protective effect of chitosan on
415 acrylamide formation in model and batter systems. *Food Hydrocolloids*, 60, 1-6.

416 SANSANO, M., CASTELLÓ, M. L., HEREDIA, A. & ANDRÉS, A. 2017. Acrylamide formation and quality
417 properties of chitosan based batter formulations. *Food Hydrocolloids*, 66, 1-7.

418 SUNG, W.-C., CHANG, Y.-W., CHOU, Y.-H. & HSIAO, H.-I. 2018. The functional properties of chitosan-
419 glucose-asparagine Maillard reaction products and mitigation of acrylamide formation by
420 chitosans. *Food Chemistry*, 243, 141-144.

421 SUYATMA, N. E., ULFAH, K., PRANGDIMURTI, E. & ISHIKAWA, Y. 2015. Effect of blanching and pectin
422 coating as pre-frying treatments to reduce acrylamide formation in banana chips. *International*
423 *Food Research Journal* 22, 936-942.

424 TAUBERT, D., HARLFINGER, S., HENKES, L., BERKELS, R. & SCHÖMIG, E. 2004. Influence of Processing
425 Parameters on Acrylamide Formation during Frying of Potatoes. *Journal of Agricultural and Food*
426 *Chemistry*, 52, 2735-2739.

427 TSAI, G.-J., SU, W.-H., CHEN, H.-C. & PAN, C.-L. 2002. Antimicrobial activity of shrimp chitin and chitosan
428 from different treatments and applications of fish preservation. 68, 170-177.

429 YUAN, Y., CHEN, F., ZHAO, G. H., LIU, J., ZHANG, H. X. & HU, X. S. 2007. A comparative study of
430 acrylamide formation induced by microwave and conventional heating methods. *J Food Sci*, 72,
431 C212-6.

432 ZENG, X., CHENG, K.-W., DU, Y., KONG, R., LO, C., CHU, I. K., CHEN, F. & WANG, M. 2010. Activities of
433 hydrocolloids as inhibitors of acrylamide formation in model systems and fried potato strips.
434 *Food Chemistry*, 121, 424-428.

435 ZHANG, Y., FANG, H. & ZHANG, Y. 2008a. Study on formation of acrylamide in asparagine–sugar
436 microwave heating systems using UPLC-MS/MS analytical method. *Food Chemistry*, 108, 542-
437 550.

438 ZHANG, Y., YING, T. & ZHANG, Y. 2008b. Reduction of Acrylamide and Its Kinetics by Addition of
439 Antioxidant of Bamboo Leaves (AOB) and Extract of Green Tea (EGT) in Asparagine–Glucose
440 Microwave Heating System. *Journal of food science*, 73, C60-C66.

441 ZHOU, Y. Y., LI, Y. & YU, A. N. 2016. The effects of reactants ratios, reaction temperatures and times on
442 Maillard reaction products of the L-ascorbic acid/L-glutamic acid system. *Food Science and*
443 *Technology*, 36, 268-274.

444 ZYZAK, D. V., SANDERS, R. A., STOJANOVIC, M., TALLMADGE, D. H., EBERHART, B. L., EWALD, D. K.,
445 GRUBER, D. C., MORSCH, T. R., STROTHERS, M. A., RIZZI, G. P. & VILLAGRAN, M. D. 2003.
446 Acrylamide Formation Mechanism in Heated Foods. *Journal of Agricultural and Food Chemistry*,
447 51, 4782-4787.