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Effective quality control of incoming potatoes as an acrylamide mitigation strategy for the French fries industry

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Abstract

The correlation between sugar levels in raw material (potatoes), brown colouring and formation of acrylamide in French fries was investigated. Such a study would allow the identification of incoming potatoes (raw material) with high potential for acrylamide-formation. Ten different potato varieties commonly used in the Western European French fries industry were stored at 8°C and samples were taken throughout the storage time. The current quality control used in the French fries industry for incoming potatoes is poorly correlated with acrylamide in the final product ($R = 0.74$). Changing the quality control parameter from colour to reducing sugars in raw material did not improve the correlation ($R = 0.72$). The best correlation was obtained with Agtron colour measurement after blanching and a two stage frying ($R = -0.88$). From this study it could be concluded that alternative entrance control measurements could provide a better mitigation of the acrylamide issue in French fries from the start of the production. These alternatives however are less cost-effective and more difficult to implement.

KEYWORDS: Acrylamide; Quality control; Colour; Reducing sugars; French fries

Introduction

Fried potato products are very familiar and popular among many gastronomic cultures. French fries (also known as chips or fries), either fresh or pre-frozen, are widely industrially produced and consumed after a final deep fat frying step. During this process, acrylamide, a probable human carcinogen is formed (IARC 1994). Exposure studies demonstrate that French fries represent a great source of dietary acrylamide for consumers (Mestdagh et al. 2007).

This process contaminant is formed during the heating process at temperatures above 120°C (Tareke et al. 2002) and is known to be linked to the Maillard browning reaction. The free amino acid asparagine and the reducing sugars (fructose and glucose) have been identified as the main precursors for its formation (Becalski et al. 2003; Mottram et al. 2002; Stadler et al. 2002). Since generally the amount of free asparagine in potato tubers largely exceeds the amount of reducing sugars, it is the latter which determines the degree of acrylamide formation and the Maillard browning upon frying (Amrein et al. 2003; De Wilde et al. 2005). Multiple factors have been demonstrated to influence the reducing sugar content in potatoes, for example, potato cultivar (Biedermann et al. 2002; De Wilde et al. 2006), storage time and temperature (Blenkinsop et al. 2002; De Wilde et al. 2005).

For the mitigation of acrylamide formation in French fries, several strategies may be considered, for instance, the selection and storage of the raw material, adaptation of processing conditions, and pre-treatments applied prior to par-frying (CIAA 2006; Foot et al. 2007). Predicting the sensitivity of incoming potatoes for the formation of acrylamide would provide a quality control tool of great aid for the French fry industry in their food safety management system. This would allow preventing the problem at the start of the production process. The current quality control at the reception point of the raw material potatoes is done based on colour evaluation with USDA/Munsell colour chart (after a short frying test, typically 180°C for 3 min) (UEITP 2007). This quality control relates raw material to colour specifications of final product (customers demand) and accordingly, either raw material is rejected for processing or appropriate process adjustments are taken (e.g. blanching conditions).

The objective of this study was to identify parameters which best predict the sensitivity of potatoes at the start of the production process for acrylamide formation during frying French fries. To our knowledge, an elaborate correlation study considering a combination of the three most obvious parameters (reducing sugars, colour and acrylamide) together in French fries has not yet been performed. Therefore, the correlation between reducing sugars in the raw material, the brown colouring and the formation of acrylamide in this fried potato product was investigated. Furthermore, threshold values (THV) were determined considering a hypothetical acrylamide limit of $500 \mu\text{g kg}^{-1}$ (based on the German system of signal values) for the most relevant parameters obtained from the correlation study. Additionally, samples were categorized based on the prediction obtained with the application of the threshold values and evaluated according to acrylamide levels of the final product.

Materials and methods

Reagents and chemicals

All reagents and chemicals used for the acrylamide and sugar analysis were described in Mestdagh et al. (2005) and De Wilde et al. (2005) respectively.

Raw material

Potato (*Solanum tuberosum* L.), varieties Bintje, Fontana and Asterix (Belgium); Russet Burbank, Lady Olympia and Markies (The Netherlands), Innovator and Victoria (France); Agria (Germany); and Maris Piper (UK) were used for the study. One lot of each variety was supplied by a single producer to be studied throughout storage. Additionally, all lots were approved for frying according to the industry entrance control criteria (size above 50 mm and minimal under water weight of 380 g). All tubers were harvested in 2007, treated with CIPC and stored at 8°C. Samples were taken on five different points in time (January-June).

Fully refined palm oil (Cargill Refined Oils-Europe) was used for all the frying experiments.

Preparation of French fries

80 Thirty five potato tubers from each variety were peeled and cut into strips (1 cm x 1 cm x 3 cm) with
81 a French fries-shaped cutter. To obtain strips with similar dimensions, parts that were in contact with the
82 outer peel of the tuber were rejected for frying. Subsequently, only the potato strips originating from the
83 central part of the potato were used for the experiment. These were washed with tap water for 1 min,
84 superficially dried on absorbent paper and divided into three groups (Figure 1). A first group, (Entrance
85 parameters) was fried at 180°C for 3 min. A second group (unblanched Final parameters) was par-fried
86 at 180°C for 90 s, frozen overnight and fried at 175°C for 150 s. The third group (blanched Final
87 parameters) included a blanching step (70°C, 20 min, ratio potato/water of 1:5 (w:w)) prior to the par-
88 frying step (as described for the unblanched). Frying and par-frying were conducted in a semi-
89 professional thermostated deep-fryer (Fritel 2505, Belgium), containing 5 L oil and equipped with a
90 stirring mechanism to ensure a homogeneous temperature in the oil bath and a digital thermometer
91 controlling the stability of the oil temperature upon frying ($\pm 1^\circ\text{C}$). Directly after frying, the French fries
92 were cooled on absorbent paper and the surface colour was measured. Finally, the fries were thoroughly
93 homogenized for subsequent acrylamide and dry matter content analysis. The repeatability of the French
94 fries preparation method was previously assessed with a RSD of 15% (Mestdagh et al. 2005).

95 *Acrylamide analysis*

96 Acrylamide was determined in homogenized potato sample by LC-MS/MS as described previously
97 (Mestdagh et al. 2005). After aqueous extraction, using [2,3,3-d₃]acrylamide as internal standard, the
98 acrylamide extract was further cleaned up by solid-phase extraction. The extract was analyzed using
99 LC-MS/MS with positive electrospray ionization.

100 *Sugar analysis*

101 Mono- and disaccharides in homogenized potato sample were assessed by GC-FID analysis as
102 described earlier (De Wilde et al. 2005). Briefly, after aqueous extraction, addition of an internal
103 standard (phenyl- β -D-glucopyranoside), clean-up and drying under nitrogen, the filtrate was derivatized
104 and injected in a GC equipped with a flame-ionization detector.

Analysis of dry matter content

The dry matter content was determined, based on an official AOAC method (1990). Briefly, 5 g of homogenized potatoes were mixed with calcinated sea sand and placed in the oven at 105°C until a constant weight was obtained.

Colour evaluation techniques

The colour of the French fries was measured using a Konica Minolta spectrophotometer CM-2500d (Konica Minolta, Osaka, Japan), operating in the CIE L*a*b* colour space, as described previously (Mestdagh et al. 2008a). Immediately after cooling down, the French fries were closely aligned in a plastic Petri dish. The readings were carried out in five-fold placing the instrument measuring port (8 mm aperture) at both sides of the dish. In such a way, the reflectance of a representative part of the surface was measured. To exclude variable cover surface conditions, the specular reflectance was included in the colour measurement. Following measurement conditions were applied: UV 100%; standard illuminant D65 and observer angle 10°. The instrument was calibrated with a white calibration tile and black calibration box. Data acquisition was performed using the Spectramagic NX colour data software, version 1.52 (Osaka, Japan).

The colour was also evaluated using an Agtron process analyzer (model E15-FP, Nevada, USA), as described previously (Mestdagh et al. 2008a). Agtron values range from 0 (black) to 100 (white). The measurement was repeated three times by shaking up the fries in between each measurement. The apparatus was calibrated using a white tile (Agtron value of 100), according to manufacturer's instructions.

Finally the colour was also evaluated using an USDA/Munsell colour chart (VIVA, Den Haag, The Netherlands) which represents the method for entrance control of raw material (potatoes) currently used in French fries industry (UEITP 2007). USDA/Munsell has a seven scoring system. The system includes 000; 00 and 0 (three different degrees of very lightly coloured French fries) followed by scores 01; 02; 03 and 04 (yellow to very brown French fries). All 35 fries from each variety were scored by comparing

130 their colour visually with the USDA/Munsell colour chart and the average score calculated.

131 *Statistical analysis*

132 Pearson correlation analysis was performed using SPSS 15.0 (SPSS inc., Chicago, IL) to determine
133 linear relationships between different parameters studied and acrylamide.

135 **Results and discussion**

136 *Reducing sugar contents of potato tubers, colour and acrylamide formation in French fries of 10*
137 *different potato varieties*

138 The present study included 10 varieties of potato tubers from Western Europe, representing the most
139 frequently used in potato processing industry. Five sampling points were taken from January to June.
140 Thus a sufficient spreading of the reducing sugar content of the raw material throughout storage could
141 be obtained, although in practice, these varieties are not necessarily processed in the potato industry
142 from January to June. Some varieties (Bintje, Victoria, Fonatana and Maris Piper) presented higher
143 levels of reducing sugars on June's sampling point, while no specific trend was found throughout the
144 initial storage period (data not shown). The reducing sugar concentrations of Asterix, Agria and Markies
145 did not change significantly throughout the whole storage period. Due to spoilage, the varieties
146 Innovator, Russet Burbank and Lady Olympia were not considered for the last sampling point. For these
147 varieties the reducing sugar contents did not change either significantly from January to May.

148 Table 1 presents the average reducing sugar contents in raw material and acrylamide formation in
149 French fries for the different potato varieties throughout storage. In addition, the min and max values of
150 reducing sugar contents before blanching are represented in between brackets for each variety. These
151 values do not necessarily correspond to the first and last sampling point for each variety. Varieties
152 Asterix and Maris Piper presented the highest reducing sugar content in raw material (averages 0.34 –
153 0.36 g 100 g⁻¹ FW), followed by Bintje, Innovator, Russet Burbank and Agria (averages 0.12 – 0.21 g
154 100 g⁻¹ FW). The lowest reducing sugar contents were observed with Lady Olympia, Victoria, Fontana

155 and Markies (averages 0.03 – 0.06 g 100 g⁻¹ FW). For the varieties which presented a higher reducing
156 sugar concentration in June's sampling point, the contribution of this last point would not have
157 influenced the variety grouping just mentioned. Since there are many factors which account for reducing
158 sugar content in potato tubers, this hinders the comparison of this parameter for every variety with those
159 reported in literature. Considering a relative comparison, Feltran et al. (2004) and De Wilde et al. (2006)
160 observed, similarly as in this study, higher concentrations of reducing sugars for the variety Asterix
161 relatively to the variety Bintje. However, both these varieties presented in this study higher reducing
162 sugar contents comparatively to De Wilde et al. (2006), in a storage experiment carried out from the
163 2003 harvest. This difference illustrates the need for careful interpretation of data, with respect to
164 possible seasonal variation or other factors influencing the level of acrylamide precursors in raw
165 potatoes. Comparing the three varieties Bintje, Agria and Markies, results showed higher concentrations
166 of reducing sugars for the variety Bintje compared to Agria and Markies presenting the lowest
167 concentration of all three. This was also observed among others (Amrein et al. 2003).

168 Blanching is an important unit operation used in French fry processing, since it influences final
169 product specifications, such as colour, fat content and texture (Moreira et al. 1999). In addition, during
170 this step acrylamide precursors are leached out resulting in the reduction of acrylamide content in the
171 final product (Mestdagh et al. 2008b). In general, potato processors increase the intensity of blanching
172 conditions towards the end of the potato season due to senescent sweetening occurrence. These
173 conditions needed to be kept constant during the course of the correlation study. Therefore blanching
174 conditions applied in this study (70°C for 20 min) result from a compromise of moderate blanching that
175 would generally be applied in the beginning of the season and a stronger treatment which would be
176 applied by the end of the season. These conditions allowed a removal of reducing sugars over 38%
177 (Table 1). This resulted in lighter coloured French fries (data not shown) and lower levels of acrylamide
178 (average 48-86% reduction) in the final product (Table 1). Percentages of reducing sugars removal were
179 not directly proportional to percentages of acrylamide reduction. For example, even though the varieties

1 180 Lady Olympia and Victoria presented the same percentage of reducing sugars removal (50% average)
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3 181 after blanching, the latest presented a higher acrylamide reduction (86% average) compared to Lady
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5 182 Olympia (53% average). This observation suggests the influence on acrylamide formation of other
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7 183 compositional parameters which vary between cultivars besides reducing sugars.

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10 184 The current quality control applied in industry at the reception of raw material potatoes (surface
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12 185 colour of fried unblanched potato strips evaluated with a USDA colour chart) was additionally
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14 186 compared to two other colour evaluation methods previously studied (Mestdagh et al. 2008a), the CIE
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17 187 L*a*b* colour parameters and a process-specific Agtron analyzer. The latest is typically used in the
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19 188 French fries industry for on-line final product quality control. Lighter coloured French fries resulted
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21
22 189 from the reducing sugars removal during blanching treatment. This has reflected in an increase of
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24 190 Agtron value and a decrease of USDA and a* values. L* and b* values did not vary significantly (data
25
26 191 not shown).

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29 192 *Correlation study between reducing sugar content of the raw material, colour and acrylamide*
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31 193 *formation in French fries*

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33 194 The correlation between sugar content in the raw material, colour and acrylamide formation in
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36 195 French fries was investigated. Figures 2-5 demonstrate that relationships between the different
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38 196 parameters evaluated in this study and acrylamide are best described as linear. Different trends were
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41 197 observed for colour parameters and acrylamide at entrance before and after blanching, Figures 2-4 (I).
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43 198 Such difference was less evident when relating final parameters with acrylamide as shown by Figures
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45 199 2-4 (II). Two factors may contribute for this variation. The influence of different frying conditions
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47 200 (one stage frying vs two stage frying and different frying temperatures) probably had an effect on
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50 201 acrylamide formation, and secondly the removal of other acrylamide precursors besides reducing
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52 202 sugars (e.g. 3-aminopropionamide) during the blanching step. On the other hand, no difference was
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55 203 observed between trends obtained with the parameter reducing sugars and acrylamide before and after
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57 204 blanching (Figure 5). Since blanching influenced the trends between the different parameters and
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acrylamide, combining the data (unblanched and blanched) for the correlation study would not be relevant. Moreover it should be realized that processed French fries are always blanched, so by keeping the data separated, the study is more representative towards the industrial practice. Therefore, Pearson correlation coefficients (R) presented in Table 2 were determined considering acrylamide results from blanched samples only. This represents the most realistic approach to find a predictor for acrylamide content in the final product.

As mentioned in literature (Amrein et al. 2003; Becalski et al. 2004; De Wilde et al. 2005; Mestdagh et al. 2008a) for potato products, a correlation between reducing sugars and acrylamide formation was found (Figure 5 and Table 2). Similarly, no link was established between sucrose and acrylamide (De Wilde et al. 2006). A better correlation was obtained between fructose and acrylamide compared to the reducing sugar glucose. Mestdagh et al. (2008), described an excess of fructose compared to glucose stimulated acrylamide formation to a higher extent than Maillard browning.

As shown on Table 2, among $L^*a^*b^*$ parameters, the best correlation was found between a^* and acrylamide. This was also observed by Mestdagh et al. (2008) although an exponential relationship between a^* and acrylamide was obtained. In that study higher levels of sugars and consequently higher contents of acrylamide were formed, giving rise to a different relationship. Both a^* and Agtron parameters presented a better correlation with acrylamide in the final product after blanching and a two stage frying ($R = 0.80$ and $R = -0.88$ respectively) compared to the short frying used for entrance control ($R = 0.77$ and $R = -0.83$ respectively). A different trend was observed with the USDA colour evaluation method. The current entrance control (short frying test 180°C , 3 min and USDA colour measurement), used for the prediction of other product specifications rather than acrylamide, is poorly correlated to acrylamide in the final product ($R = 0.74$). This method allows only a five grade classification scale. Moreover, such classification is rather subjective since it is done by comparing visually the colour of the product with the colour chart. Analyzing reducing sugars in raw material (based on fresh weight) does not improve the correlation with the acrylamide of the final product ($R = 0.72$). A better correlation is

obtained with Agtron process analyzer after frying at 180°C for 3 min ($R = -0.83$). Agtron colour measurements after blanching (70°C, 20 min) and a two stage frying (180°C, 90 s and 175°C, 150 s) obtained the best correlation regarding acrylamide in final product ($R = -0.88$).

Based on the raw material used and the process conditions (blanching and frying) applied in this study, colour evaluation with Agtron allowed a better correlation with acrylamide compared to the reducing sugar contents. For the practical implementation in the food industry, using a colour parameter as an acrylamide predictor in raw material is more practical than analyzing sugar contents. However, results indicate that the current quality control of raw material potatoes, can be improved towards acrylamide prediction by changing colour evaluation method from USDA colour chart to the Agtron process analyzer.

The correlation study combined with a specific acrylamide level in French fries could provide an extra preventive tool in their food safety management system, based on threshold values (THV) of the evaluated parameters best related to acrylamide. Such approach applied as a quality control measurement for raw potatoes at the reception point could prevent the acrylamide problem during further production.

Evaluation of threshold values

The correlation study discussed above revealed the parameter best correlated to acrylamide formation in French fries was obtained with Agtron measurements. Reducing sugars are also a relevant parameter since they are chemically known to be the limiting precursor for acrylamide formation in potatoes. On the other hand USDA is the current quality control tool used for the approval or rejection of incoming potatoes in French fry industry. Consequently, these relevant parameters were considered for the determination of THV presented in Table 3. The calculation of such values was based on the linear relationships obtained between the different parameters with the acrylamide formed in the final product and considering a hypothetical acrylamide limit of 500 $\mu\text{g kg}^{-1}$. Relationships between colour

parameters and acrylamide are represented by the broken line on Figures 2-3 (I - entrance parameters and II - final parameters) and relationships between reducing sugars and acrylamide on Figure 6 (solid line - entrance parameter and broken line - final parameter). The hypothetical acrylamide limit was selected based on the most recent signal value ($530 \mu\text{g kg}^{-1}$) established for French fries /chips by the German minimization concept for acrylamide. The signal value is defined as the lowest level of the 10% of products of each commodity group that have the highest acrylamide content (Göbel and Kliemant 2007). The denominations “acceptable” (acrylamide $<500 \mu\text{g kg}^{-1}$) and “rejectable” (acrylamide $>500 \mu\text{g kg}^{-1}$) will be adopted throughout the discussion of the results. In practice, incoming potatoes that would be classified as “rejectable” (within a certain limitation) would not be necessarily rejected but rather subjected to a more rigorous blanching treatment. This would allow further sugar removal thus rendering the French fries less prone to acrylamide formation and suit final product specifications (acrylamide $<500 \mu\text{g kg}^{-1}$). The application of the THV to the samples analyzed in this study resulted in a preliminary analysis of sample categorization (Table 3). Samples which are categorized as “acceptable” and have acrylamide $>500 \mu\text{g kg}^{-1}$ (third column of Table 3) could represent a non-conformity. On the other hand, samples which are categorized as “rejectable” and present acrylamide levels $<500 \mu\text{g kg}^{-1}$ (fifth column on Table 3) would have been in conformity (in respect to the acrylamide limit). Both scenarios are undesirable, however the first scenario could compromise final consumer safety, and the second scenario represents unnecessary “extra-precautions for industry” (e.g., extra blanching) which translates in unnecessary costs.

The highest percentage of rejected samples (33%) was obtained with the application of the USDA THV after a short frying test (USDA <2.1). Worth noticing is the fact that 50% of those rejected samples correspond to samples “unnecessarily rejected”. Similarly, the application of the Agron THV (>57) after the short frying test presented a high percentage of samples rejected with acrylamide $<500 \mu\text{g kg}^{-1}$ (45%). This value was reduced to 17% with the application of the THV for reducing sugars in raw potatoes ($<0.25 \text{ g } 100 \text{ g}^{-1} \text{ FW}$), although it should be noted that the number of samples in this

1 280 category was too small to draw final conclusions.

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3 281 On the other hand, considering the application THV for the final parameters (after blanching and fried
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5 282 in two stages) different trends were obtained. The application of a THV for USDA <1.6 remains a poor
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7 283 tool for predicting acrylamide in the final product, meaning that 56% of rejected samples had
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10 284 acrylamide levels <500 µg kg⁻¹. Applying a THV for reducing sugars <0.11 g 100 g⁻¹ FW in blanched
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12 285 potatoes increased the percentage of rejected samples with acrylamide <500 µg kg⁻¹ from 17% to 25%.
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14 286 In contrast, the application of a THV for Agtron >61.0 showed major improvements. This application
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17 287 resulted in a reduction of “unnecessarily rejected” samples to only 22% leading to the highest
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19 288 percentage of correctly categorized samples (93%). Although this investigation was done on a lab scale,
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22 289 and in addition a sensory evaluation of the final product was not considered, the THV obtained for
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24 290 Agtron in the final product fits within the range of limits of consumer acceptability. Generally
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26 291 considered, the final product colour is too bright at Agtron values above 75 and too dark below 55
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28
29 292 (Mestdagh et al. 2008a).

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31 293 When selecting a quality control parameter for raw material potatoes at the reception for acrylamide
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33 294 mitigation purposes, an important aspect to consider when evaluating the THV application is the final
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36 295 consumer safety (percentage of accepted samples with acrylamide >500 µg kg⁻¹). These percentages
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38 296 ranged from 3 to 12% for the parameters presented on Table 3. The lowest percentage (3%) was
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41 297 obtained with the application of the THV for Agtron final (after blanching and fried in two stages). The
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43 298 parameter USDA final (after blanching and fried in two stages) allowed the highest percentage of
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45 299 accepted samples with acrylamide >500 µg kg⁻¹ (12%).
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48 300 It should be kept into account that the THV for quality control tools mentioned in this paper are
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50 301 directly related to the hypothetical 500 µg kg⁻¹ acrylamide level and thus are limited to the blanching
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52 302 and frying conditions used in this study. As such, the THV mentioned should not be considered as
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55 303 absolute. Because of the impact of final frying on acrylamide formation, an approach in which more
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57 304 appropriate selection criteria of the raw material combined with informative advices given to consumers
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and catering may contribute to safer French fries.

The preliminary data obtained in this study and the threshold values concept presented, demonstrate that from a food safety point of view, a more optimal quality control could be adopted for incoming potatoes in order to guarantee reduced acrylamide contents in the final product. Agtron measurement after blanching and a two stage frying, or, measuring reducing sugars of the incoming product could provide a preventive tool for French fry industry to evaluate the acrylamide problem at the start of the production. It should be emphasized that implementing these alternatives of quality control in for instance a food safety management system on company level, would require the input of supplementary resources, having an impact on total production cost and cost-effectiveness of these possible mitigation tools.

Since acrylamide formation is dependent on the surface area of the potato product and on the process conditions applied, the extrapolation of results for other type of potato products with different surface-to volume ratios, such as potato crisps, should not be considered.

Moreover, due to the multiple pre and post-harvest factors that may impact the final amounts of the precursors in the raw material to acrylamide in French fries, this study should be repeated/validated throughout different seasons. Work is currently been carried out for the 2008 harvest season.

Abbreviations used

DM, dry matter; FW, fresh weight; AA, acrylamide; RS, reducing sugars; THV, threshold value; USDA, United States Department of Agriculture.

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390 **Figure captions**

391 Figure 1. Experimental setup used for the correlation study between reducing sugars in raw material,
392 colour and acrylamide formation in French fries.

393
394 Figure 2. Relation between USDA (I – after short frying test; II - after two stage frying) and acrylamide
395 content (determined after two stage frying) in unblanched (filled square, solid line) and blanched (open
396 square, broken line) French fries.

397
398 Figure 3. Relation between Agron (I – after short frying test; II - after two stage frying) and acrylamide
399 content (determined after two stage frying) in unblanched (filled square, solid line) and blanched (open
400 square, broken line) French fries.

401
402 Figure 4. Relation between a* colour (I – after short frying test; II - after two stage frying) and
403 acrylamide content (determined after two stage frying) in unblanched (filled square, solid line) and
404 blanched (open square, broken line) French fries.

405
406 Figure 5. Relation between reducing sugars content in raw potatoes and acrylamide content in French
407 fries (after two stage frying) without blanching (filled square, solid line) and after blanching (open
408 square, broken line).

409
410 Figure 6. Relation between reducing sugars content in raw potatoes without blanching (filled square,

411 solid line) and after blanching (open square, broken line) with acrylamide content in French fries (after
412 blanching and two stage frying).

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413 **Table captions**

414 Table 1. Average dry matter (DM), reducing sugars content (RS) and acrylamide (AA) formation in
415 French fries before and after blanching treatment for different potato varieties throughout storage. RS
416 contents between brackets represent min and max values.

417
418 Table 2. Pearson correlation coefficients (R) between respectively entrance parameters (reducing
419 sugars-raw material; colour-1 stage frying) and final parameters (reducing sugars-blached raw
420 material; colour-after blanching and two stage frying) and acrylamide (after blanching and two stage
421 frying) levels in French fries.

422
423 Table 3. Threshold values determination for entrance parameters (reducing sugars-raw material; colour-
424 after one stage frying) and final parameters (reducing sugars-blached raw material; colour-after
425 blanching and two stage frying), based on a hypothetical acrylamide limit of 500 $\mu\text{g kg}^{-1}$ and their
426 application to samples of the present study regarding the acrylamide formation in French fries.

Figure 1. Experimental setup used for the correlation study between reducing sugars in raw material, colour and acrylamide formation in French fries.
213x84mm (96 x 96 DPI)

Figure 2. Relation between USDA (I – after short frying test; II - after two stage frying) and acrylamide content (determined after two stage frying) in unblanched (filled square, solid line) and blanched (open square, broken line) French fries.
200x94mm (96 x 96 DPI)

Figure 3. Relation between Agtron (I – after short frying test; II - after two stage frying) and acrylamide content (determined after two stage frying) in unblanched (filled square, solid line) and blanched (open square, broken line) French fries.
196x95mm (96 x 96 DPI)

Figure 4. Relation between a* colour (I – after short frying test; II - after two stage frying) and acrylamide content (determined after two stage frying) in unblanched (filled square, solid line) and blanched (open square, broken line) French fries.
200x91mm (96 x 96 DPI)

Figure 5. Relation between reducing sugars content in raw potatoes and acrylamide content in French fries (after two stage frying) without blanching (filled square, solid line) and after blanching (open square, broken line).
102x89mm (96 x 96 DPI)

Figure 6. Relation between reducing sugars content in raw potatoes without blanching (filled square, solid line) and after blanching (open square, broken line) with acrylamide content in French fries (after blanching and two stage frying).
102x91mm (96 x 96 DPI)

	Before blanching treatment			After blanching treatment		
	DM	RS	AA	DM	RS	AA
	%	(g 100 g ⁻¹ FW)	(µg kg ⁻¹)	%	(g 100 g ⁻¹ FW)	(µg kg ⁻¹)
Maris Piper	20.7	0.36 (0.25-0.50)	1114	17.4	0.17	454
Asterix	19.4	0.34 (0.25-0.50)	1409	18.8	0.14	727
Bintje	20.9	0.21 (0.11-0.36)	716	18.5	0.13	305
Russet Burbank	20.5	0.16 (0.06-0.21)	900	17.4	0.08	375
Innovator	21.6	0.15 (0.13-0.19)	616	19.9	0.06	211
Agria	19.3	0.12 (0.08-0.17)	919	17.5	0.05	341
Victoria	16.6	0.06 (0.03-0.10)	534	15.3	0.03	73
Fontana	19.7	0.06 (0.03-0.14)	291	18.6	0.03	141
Lady Olympia	19.4	0.04 (0.02-0.05)	382	17.9	0.02	180
Markies	20.2	0.03 (0.01-0.03)	148	19.2	0.01	61

Table 1. Average dry matter (DM), reducing sugars content (RS) and acrylamide (AA) formation in French fries before and after blanching treatment for different potato varieties throughout storage. RS contents between brackets represent min and max values.
135x91mm (150 x 150 DPI)

	Parameter	R
Entrance	USDA	0.74 ^a
	Agtron	-0.83 ^a
	L*	-0.63 ^a
	a*	0.77 ^a
	b*	-0.46 ^b
	RS (g 100 g ⁻¹ FW)	0.72 ^a
	Fructose (g 100 g ⁻¹ FW)	0.75 ^a
	Glucose (g 100 g ⁻¹ FW)	0.70 ^a
	Sucrose (g 100 g ⁻¹ FW)	0.00 ^b
Final	USDA	0.68 ^a
	Agtron	-0.88 ^a
	L*	-0.59 ^a
	a*	0.80 ^a
	b*	-0.22 ^b
	RS (g 100 g ⁻¹ FW)	0.78 ^a
	Fructose (g 100 g ⁻¹ FW)	0.83 ^a
	Glucose (g 100 g ⁻¹ FW)	0.65 ^a
	Sucrose (g 100 g ⁻¹ FW)	0.29 ^b
		^a p <0.01; ^b p <0.05

Table 2. Pearson correlation coefficients (R) between respectively entrance parameters (reducing sugars-raw material; colour-one stage frying) and final parameters (reducing sugars-blached raw material; colour-after blanching and two stage frying) and acrylamide (after blanching and two stage frying) levels in French fries.
176x173mm (96 x 96 DPI)

	Threshold values	N ^o accepted samples	N ^o accepted samples and AA >500 $\mu\text{g kg}^{-1}$	N ^o rejected samples	N ^o rejected samples and AA <500 $\mu\text{g kg}^{-1}$	% Correctly categorized samples
Entrance	USDA <2.1	28	1	14	7	81
	RS <0.25 g 100 g ⁻¹ FW	33	2	6	1	92
	Agtron >57	31	2	11	5	83
Final	USDA <1.6	33	4	9	5	79
	RS <0.11 g 100 g ⁻¹ FW	34	2	8	2	90
	Agtron >61	33	1	9	2	93

Table 3. Threshold values determination for entrance parameters (reducing sugars-raw material; colour- after one stage frying) and final parameters (reducing sugars-blanching raw material; colour- after blanching and two stage frying), based on a hypothetical acrylamide limit of 500 $\mu\text{g kg}^{-1}$ and their application to samples of the present study regarding the acrylamide formation in French fries.

182x83mm (96 x 96 DPI)