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Selection Criteria for Potato Tubers To Minimize Acrylamide Formation during Frying

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A number of parameters linked to the selection of potato tubers were evaluated with regard to their potential to influence acrylamide formation in French fries. The formation of acrylamide, which is a potential human carcinogen, can be minimized for a big extent by the selection of an appropriate tuber. This study focused on the following selection criteria: variety as influenced by storage time and soil type, underwater weight, and tuber size. A total of 16 varieties were compared, concerning their potential for acrylamide formation. From that survey, certain varieties, such as Tebina and Quincy, could be appointed as unsuitable for frying. The differences in the potential of acrylamide formation between the varieties could mainly be explained by the reducing sugar content of the potato ($R^2 = 0.82$, $n = 96$). The investigated type of soil and storage time at 8 °C appeared to have a minor influence on the acrylamide formation during frying. On the other hand, the tuber size of the potato did contribute in a significant manner to the acrylamide formation. Smaller tubers were more susceptible to acrylamide formation and should be avoided in the frying process. The last selection parameter, the underwater weight, appeared to be of minor importance in the acrylamide formation. On the basis of these simple selection criteria, it is possible to make a first screening of potatoes to reduce the acrylamide formation during frying.

KEYWORDS: Acrylamide; potato; variety; soil; maturity; tuber size; underwater weight

INTRODUCTION

Acrylamide is a compound that is produced for use in the manufacture of polymers as well as various other materials. While acrylamide is used in the manufacturing of certain food packagings, this use has not been found to add acrylamide to foods at levels that could pose a health concern. In 2002, however, the Swedish National Food Administration detected high concentrations of acrylamide in common heated starch-rich foods such as French fries (*1*). Acrylamide is genotoxic and a potential carcinogen to humans, classified in Group 2A by the IARC (*2*). It has been established that acrylamide is generated during the Maillard reaction. Crucial participants in this reaction are asparagine and a carbonyl compound (*3*−*6*). For many consumers, French fries are the predominant source of acrylamide exposure (*7*).

The potato (*Solanum tuberosum* L.), which is rich in asparagine, is very susceptible to acrylamide formation during heating at temperatures above 120 °C. Asparagine is a very important precursor in the acrylamide formation; however, reducing sugars are the limiting reagent in potato products and will therefore determine the acrylamide formation in fries to a big extent (*8*−*11*).

For the mitigation of the acrylamide formation during frying, some precautionary measures can be taken. The frying process can be modified or the raw material can be selected to obtain a lower acrylamide concentration. The selection of the raw material is mainly based on the composition of the potato. The aim of this study was to identify relevant criteria to select potatoes that have a lower potential for acrylamide formation during frying. To explore the factors that are responsible for this lower acrylamide formation, potatoes were subjected to a chemical analysis. In this study, three different selection

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parameters were evaluated. First, the interspecies variability, which is studied on 16 different varieties grown on two types of soil. The second selection parameter is the tuber size of the potato. Finally, the influence of the underwater weight on the composition of the potato and on the acrylamide formation is tested. Using these factors, potato processors can apply extra criteria for the selection of the raw material, to minimize acrylamide formation during frying.

MATERIALS AND METHODS

Samples. Different potato (*S. tuberosum* L.) varieties were obtained from the Interprovincial Research Institute for Potato Production (Rumbeke-Beitem, Belgium). For the comparison of different varieties, 11 French fry varieties were used from the harvest of 2003: Bintje, Agrinova, Asterix, Daisy, Florida, Fontane, Hommage, Quincy, Ramos, Tebina, and Voyager and 5 crisp varieties: Saturna, Jupiter, Lady Claire, Lady Jo, and Lady Rosetta. The economically most important variety in Belgium is Bintje, which represents 63% of the market. It is very popular as a result of its versatility because it can be used for several applications other than frying. Ramos shows very good perspectives concerning storage at 6 °C, which makes storage without sprout suppressor possible. Saturna is the reference variety for crisp production and represents 6% of the Belgian market. Fontane was selected for its easy breeding and, subsequently, for its multiple use apart from frying. This is also an important variety in Germany and The Netherlands. Asterix is a good frying variety and has good boiling characteristics. In addition, other varieties were also included as an extension of the yearly evaluation of various potato varieties carried out by the Interprovincial Research Institute for Potato Production in Belgium, because of their promising characteristics. These varieties, except Voyager, which was grown in only one type of soil (sandy loam soil), were cultivated on two types of soil, a clay soil (Waterland-Oudeman, Belgium) and a sandy loam soil (Ieper, Belgium). A sandy loam soil normally has lower water and nutrient-holding capacities and is probably more permeable and better aerated than a clay soil. The sum of the precipitation during the growing period was 328 L m^{-2}. The average monthly temperature during the growing season varied from a minimum of 8.1 °C to a maximum of 19.8 °C in respectively March and August. The applied fertilization rate was as followed: 180 and 213 kg N ha^{-1}. The potatoes were harvested in October of the year 2003. After the potatoes were harvested, they were stored at 8 °C and treated with CIPC (Chlorpropham, isopropyl-*N*-(3-chlorophenyl)carbamate) at 1.5 kg of Luxan-Grostop (1.34% active substance) ton^{-1} potatoes. Sampling was carried out every 5 weeks starting only in the second week of January. Sampling started late because of the fact that the variation in the composition of the potato is very small at the beginning of storage when potatoes reached maturity at harvest (*11*). Samples were taken in January, February, March, and May. To assess the influence of the tuber size, the variety Bintje was used immediately after harvesting in October 2004. Two categories of size were used, <50 mm and >50 mm. Finally, the influence of the underwater weight was also assessed on the variety Bintje of the 2004 harvest. Three categories were used, 328 g 5 kg^{-1} washed potatoes [specific gravity (SG) = 1.070], 379 g 5 kg^{-1} washed potatoes (SG = 1.082), and 395 g 5 kg^{-1} washed potatoes (SG = 1.086).

Sample Preparation and Frying. For the comparison of the varieties, potatoes were rinsed and fried for acrylamide determination as described by De Wilde et al. (*11*). The rest of the potatoes were cut in small cubes and kept at −18 °C to analyze the chemical composition of the raw material.

To test the influence of tuber size and underwater weight, the original frying procedure was modified as follows. Cut potatoes (one fry out of one tuber, in total 20 fries) were rinsed 5 times in 400 mL of water. After superficial drying, the batch of 20 fries was divided into two equal batches of 10 French fries. Fries were prepared during exactly 5 min with a Fritel Frying (Hasselt, Belgium) machine of 3.2 kW and a capacity of 5 L of oil at 180 (±1 °C). A mixer was put in the frying oil for a better distribution and stabilization of the heat (*12*). The temperature was monitored with a digital thermometer. After the potatoes were fried and cooled, they were homogenized with a Braun-multiquick mixer (500 W) and frozen at −18 °C until analyzed for their acrylamide content.

Repeatability of the Frying Process. The French fries used for this experiment originated from one single batch of potato cuts. Two repeatability tests were performed. The first test used in the study of differences between varieties was already described in De Wilde et al. (*11*). The second test was carried out for the modified frying process with a homogeneous distribution of the heat. The frying process was repeated 10 times on the same day.

Reagents and Chemicals. All reagents and chemicals used in the following chemical analysis were already described in De Wilde et al. (*11*).

Chemical Characterization of the Potato. *Dry Matter (DM) Content.* The determination of the DM content was based on the AOAC Official Method (930.15) (*13*). Briefly, 5 g of homogenized potatoes were mixed with calcined sea sand and placed in the oven at 105 °C until a constant weight was obtained.

Crude Protein Content. The total Kjeldahl nitrogen content was determined according to Egan et al. (*14*). Crude potatoes were homogenized with a household mixer (Braun MR 5550 MCA). An amount of 1.5−2 g of this potato mix was transferred into a Kjeldahl tube to which 10 mL of H_2SO_4 and one Kjeltab CX (catalyst compound) were added. The digestion was done in a destruction block (420 °C) until a clear solution was obtained. Distillation was carried out with a 2200 Kjeltec Auto (FOSS Tecator, Sweden). The obtained distillate was titrated with 0.05 M HCl. The crude protein content was calculated by multiplying the total nitrogen content, consisting of soluble and insoluble forms, with a conversion factor of 6.25.

Free Amino Acid Content. Mixed crude potatoes (15 g) were transferred into a quantitative flask of 100 mL and diluted to 100 mL with 15% trichloroacetic acid (TCA, v/v). After incubation (10 min at ambient temperature) and filtration, the filtrate was diluted into the injection buffer and used in the Biotronik LC3000 amino acid analyzer with a two-channel detector (Eppendorf, Hemburg, Germany). The separation of the amino acids is based on a different partition of the amino acid cations between a cation-exchange resin and five consecutively used lithiumacetate buffer solutions of an increasing pH and ionic strength. The column used was a stainless steel column (100 × 4.1 mm) filled with a cation-exchange resin (5 μg), consisting of a sulfonated polystyrene matrix, cross-linked with diphenyl benzene. The detection of the separated amino acids is based on a color reaction using a buffered ninhydrin solution and a continuous measurement of the absorbance at 570 and 440 nm (*11*).

Sugars. Mono- and disaccharides were assessed by gas chromatographic analysis after an aqueous extraction from homogenized potatoes with the addition of an internal standard (phenyl-β-D-glucopyranoside). After filtration and evaporation, the residue was derivatized in two steps: first, an oximation with 100 μL of oximation reagents (30 min at 60 °C) and, second, to trimethylsilylesters with 100 μL of hexamethyldisilizane and 10 μL of trifluoracetic acid (10 min at ambient temperature). Analyses were carried out using a Varian 3380 gas chromatograph equipped with a flame-ionization detector (Varian Instrument Group, Walnut Creek, CA) and a stationary phase, (5% phenyl)methylpolysiloxane, with a film thickness of 0.25 μm, 30 m × 0.32 mm I.D. (Agilent Technologies, Palo Alto, CA) as described in De Wilde et al. (*11*).

Acrylamide. The determination of acrylamide was carried out using an accreditated method based on the ISO 17025 standards with minor modifications described in De Wilde et al. (*11*). Acrylamide was extracted from food with water before the cleanup step. A further concentration step by evaporation was introduced before chromatographic separation on a μ-Bondapak C_{18} 300 × 3.9 mm, 10 μm analytical column (Waters Corporation, Milford, MA) with 0.1% acetic acid in water as the mobile phase at a flow rate of 0.6 mL min^{-1}. A split of the flow rate (1:1) with a Valco piece was applied before the entrance into the MS/MS detector consisting of a Quattro *micro* triple quadrupole system from Micromass (Manchester, U.K.). Determination of acrylamide in samples was made by a linear calibration curve set on standard solutions over a concentration range from 0 to 1000 μg kg^{-1} using 2,3,3-[D3]-acrylamide (daughter ion: 75 > 58) as the

Table 1. Average Chemical Composition ($n = 4$) of 16 Potato Varieties Grown on a Sandy Loam Soil and Average Acrylamide Concentration after Frying of 16 Potato Varieties[a] Grown on Sandy Loam and Clay Soil

	reducing sugars (% on DM)	sucrose (% on DM)	dry matter (%)	crude protein (% on DM)	total free amino acids (% on DM)	asparagine (% on DM)	acrylamide (μg kg^{-1})	
							sandy loam soil	clay soil
Agrinova	0.20 abcd[b]	0.69 ab	22.51 a	9.48 abc	3.42 def	1.37 efg	247 cd	226 b
Asterix	0.47 e	0.80 ab	23.77 abc	8.18 a	2.19 a	0.72 a	403 f	155 ab[c]
Bintje	0.25 cd	0.62 ab	22.15 a	11.11 e	3.53 def	1.33 efg	296 de	200 ab
Daisy	0.19 abc	0.87 ab	23.04 abc	10.65 cd	3.09 bcde	1.02 abcde	131 ab	162 ab
Florida	0.22 bcd	0.76 ab	25.14 de	9.09 ab	2.53 abc	0.96 abcd	214 bcd	128 ab[c]
Fontane	0.13 abc	0.65 ab	22.87 a	10.27 cd	3.38 def	1.37 efg	119 ab	228 b[c]
Hommage	0.26 cd	1.02 b	23.84 abcd	10.44 cd	2.41 ab	0.88 abc	182 abc	497 c[c]
Jupiter	0.08 ab	0.64 ab	24.49 bcd	11.06 e	2.87 abcd	1.48 fg	147 abc	148 ab
Lady Claire	0.04 a	0.68 ab	23.42 ab	11.84 f	3.78 ef	1.64 g	104 a	116 a
Lady Jo	0.09 abc	0.51 a	23.93 cd	11.49 e	3.38 def	1.37 efg	144 abc	149 ab
Lady Rosetta	0.16 abc	0.79 ab	25.99 e	10.52 bcd	2.37 ab	0.81 ab	140 ab	228 b
Quincy	0.33 de	0.68 ab	24.13 abcd	9.59 abc	3.01 bcde	1.17 cdef	347 ef	654 d[c]
Ramos	0.11 abc	0.67 ab	23.49 abcd	10.08 bcd	3.31 def	1.39 fg	158 abc	109 a
Saturna	0.08 ab	0.73 ab	25.25 de	10.94 e	2.98 bcde	1.39 def	125 ab	166 ab
Tebina	0.68 f	0.64 ab	22.67 ab	8.73 a	3.25 cde	1.08 bcdef	1021 g	880 e
Voyager	0.11 abc	0.54 a	22.78 abc	11.20 e	4.08 f	1.39 fg	115 ab	ND[d]

[a] Stored at 8 °C over 8 months. Results are the average over 8 months as explained in the Results and Discussion. [b] Different letters in one column indicate significant differences ($p \leq 0.05$) by the Duncan test. [c] Varieties with a significant difference in acrylamide formation after frying of potatoes cultivated on two types of soil. [d] ND = not determined.

internal standard for the recovery correction. The limits of the method are, respectively, 10 and 20 μg acrylamide kg^{-1} foodstuff for detection and quantification (*15*).

Statistical Analysis. Statistical analysis of the data was performed using SPSS version 12.0 (SPSS, Inc., Chicago, IL). A general linear model, univariate analysis was performed to determine significant influences ($p \leq 0.05$) of parameters (i.e., variety, storage time, and soil type) on intrinsic factors (i.e., DM content, reducing sugar content, etc.). A post hoc comparison of means (Duncan) was carried out to determine significant differences between the different levels within each treatment. The term significant is used to indicate differences for which $p \leq 0.05$.

RESULTS

Preliminary Experiments. The repeatability of the French fry preparation method of the different varieties was already assessed in De Wilde et al. (*11*). An average acrylamide concentration of 364 μg kg^{-1} was obtained, with a relative standard deviation of 27% ($n = 10$) (results not shown). The second frying process was a modification of the first by placing a mixer in the oil for a better heat diffusion. An average acrylamide concentration of 191 μg kg^{-1} was obtained, with a relative standard deviation of 15% ($n = 10$) (results not shown). The absolute acrylamide values cannot be compared because another potato batch was used.

Selection Criteria: Influence of Storage Time, Variety, and Type of Soil on the Chemical Composition of the Potato. Besides the main acrylamide precursors (reducing sugars and free asparagine), the DM content, crude protein, total free amino acid content, and the whole set of free amino acids were determined for almost all of the potato samples. The influence of the soil type on the chemical composition during storage was only studied for varieties Bintje, Ramos, and Saturna. The influence of the soil type on the chemical composition of the other varieties was only studied after 4 months of storage. Subsequently, all samples were fried as described, and the acrylamide concentration was determined. Crisp varieties were prepared as French fries as well to compare them for acrylamide formation with the other varieties.

Reducing Sugars. During storage time, the fructose and glucose concentration of all varieties did not change significantly in time (results not shown). The reducing sugar concentrations (fructose and glucose) of all varieties of the tubers grown on a sandy loam soil are presented in **Table 1**, as the average value of the four sampling dates (fructose and glucose). The variety Tebina showed the highest value, i.e., 0.68% on DM, and was significantly different from all other varieties. The variety Lady Claire appeared to contain the lowest amount of reducing sugars, i.e., 0.04% on DM. Varieties used for the production of potato chips (Saturna, Jupiter, Lady Rosetta, Lady Jo, and Lady Claire) were generally low in reducing sugars. Varieties can roughly be divided into three groups: varieties with reducing sugar concentrations higher than 0.4% on DM, Tebina and Asterix; varieties with concentrations between 0.2 and 0.4% on DM, Agrinova, Bintje, Florida, Hommage, and Quincy; and varieties with a concentration lower than 0.2% on DM, Daisy, Fontane, Lady Rosetta, Voyager, Ramos, Lady Jo, Saturna, Jupiter, and Lady Claire. Results were similar for tubers grown on a clay soil (results not shown).

The soil type appeared to have an insignificant influence on the reducing sugar content for all varieties after 4 months of storage (results not shown). The sugar concentrations were not significantly higher or lower on one type of soil.

Sucrose, DM, Crude Protein, Total Free Amino Acid, and Asparagine Content. All of the above-mentioned parameters remained constant during storage. No significant differences could be detected in the sucrose, crude protein, total free amino acid, and asparagine content in potatoes grown on two different types of soil. The DM content on the other hand appeared to be significantly higher in tubers grown on a sandy loam soil. The average over storage time of the above-mentioned parameters are presented in **Table 1** for all of the varieties cultivated on the sandy loam soil.

Influence of the Tuber Size and the Underwater Weight of the Tuber on the Chemical Composition of the Potato. Average concentrations ($n = 10$) of the tuber compounds of tubers from two different sizes are presented in **Table 2**. These data cannot be compared with the data in **Table 1**, because those tubers do not originate from the same field and farmer. The crude protein, asparagine, and total free amino acid contents were not significantly influenced by the size of the tuber. The

Table 2. Influence of Tuber Size on the Average Chemical Composition and Acrylamide Concentration after Frying of the Variety Bintje ($n = 10$)

	tuber size	
	<50 mm	>50 mm
DM (%)	17.64 a[a]	20.28 b
crude protein (% on DM)	11.96 a	10.70 a
fructose (% on DM)	0.65 b	0.09 a
glucose (% on DM)	0.98 b	0.10 a
sucrose (% on DM)	1.55 b	0.51 a
reducing sugars (% on DM)	1.62 b	0.19 a
total free amino acid (% on DM)	4.20 a	4.25 a
asparagine (% on DM)	2.92 a	2.90 a
acrylamide (μg kg^{-1})	322 b	148 a

[a] Different letters in one row indicate significant differences ($p \leq 0.05$) by the Duncan test.

Table 3. Influence of Underwater Weight on the Chemical Composition and Acrylamide Concentration after Frying of the Variety Bintje ($n = 3$)

	underwater weight (g 5 kg^{-1} tubers)		
	328	378	395
DM (%)	18.34 a[a]	19.36 b	21.06 c
crude protein (% on DM)	11.60 ab	11.94 b	10.97 a
fructose (% on DM)	0.15 b	0.11 ab	0.08 a
glucose (% on DM)	0.18 b	0.14 a	0.13 a
sucrose (% on DM)	0.70 a	0.80 a	0.73 a
reducing sugars (% on DM)	0.33 b	0.25 a	0.22 a
total free amino acid (% on DM)	5.88 a	5.23 a	5.27 a
asparagine (% on DM)	2.06 a	2.05 a	1.91 a
acrylamide (μg kg^{-1})	268 a	212 a	260 a

[a] Different letters in one row indicate significant differences ($p \leq 0.05$) by the Duncan test.

DM, fructose, glucose, and sucrose contents on the other hand were significantly different between two tuber sizes. Smaller tubers were richer in reducing sugars and sucrose but had a lower DM content. Smaller tubers contained a reducing sugar concentration of 1.62% on DM, while larger tubers only contained a concentration of 0.19% on DM.

Because the underwater weight is strongly correlated with the DM content, it is obvious that the DM content increased with an increasing underwater weight (**Table 3**). The crude protein, total free amino acid, sucrose, and asparagine contents appeared not to be influenced by differences in the underwater weight. A significant decrease in the reducing sugar content was observed with an increasing underwater weight (**Table 3**).

Acrylamide: Influence of Storage Time, Variety, and Type of Soil on Acrylamide Formation. Concerning storage time, the acrylamide formation during frying did not fluctuate over 8 months of storage for almost all of the varieties (results not shown). No significant decreasing changes appeared in storage time.

The acrylamide concentrations in French fries prepared from 16 varieties grown on a sandy loam soil are presented in **Table 1** as the average value of all storage periods ($n = 4$). The variety Tebina is significantly different from all other varieties. This variety shows a remarkably high acrylamide formation during frying, namely, 1020 μg kg^{-1}. This is more than twice as high than the variety Asterix, which has the second highest acrylamide value, 403 μg kg^{-1}. Roughly, the varieties can be divided into three subgroups, in particular, the group with the highest potential for acrylamide formation (>600 μg kg^{-1}), which contains the variety Tebina. The second group with values between (200−600 μg kg^{-1}) contains varieties Agrinova, Asterix, Bintje, Florida, and Quincy. The variety Asterix however was significantly different from varieties Agrinova, Bintje, and Florida. The group with the lowest amount of acrylamide concentration (<200 μg kg^{-1}) after frying contains the varieties Daisy, Fontane, Hommage, Jupiter, Lady Claire, Lady Jo, Lady Rosetta, Ramos, Saturna, and Voyager. These latter varieties were not significantly different from each other.

When comparing both types of soil, significant differences are found for the varieties Asterix, Florida, Fontane, Hommage, and Quincy (**Table 1**). Varieties Asterix and Florida appeared to have a higher potential for acrylamide formation when grown on a sandy loam soil, while varieties Hommage, Fontane, and Quincy showed a higher potential for acrylamide formation when grown on a clay soil. The acrylamide formation during frying of tubers from the other 10 varieties was not significantly influenced by the type of soil.

Influence of the Tuber Size and Underwater Weight of the Tuber on Acrylamide Formation. The potential of acrylamide formation is much higher in smaller tubers (**Table 2**), with a value of 322 μg kg^{-1}, compared to 148 μg kg^{-1} in larger tubers. The underwater weight of the tuber had a minor, not significant influence on the acrylamide formation (**Table 3**). The values ranged from 212 to 268 μg kg^{-1} for potatoes with an underwater weight of 378 and 395 g 5 kg^{-1} tubers, respectively.

DISCUSSION

In the preliminary experiment, again, the importance of a perfectly controlled frying system is illustrated to ensure and reproduce acrylamide generation during frying. When a more homogeneous distribution of the heat is ensured, a spectacular improvement of the repeatability is obtained.

Influence of Storage Time, Variety, and Type of Soil on the Chemical Composition of the Potato. Concerning the influence of storage time on the chemical composition of the tubers, it could be concluded that none of the investigated parameters changed significantly during storage. This is in accordance with the results of De Wilde et al. (*11*). However, in conditions of constant temperature, the sugar content may increase during longer storage periods because of the degradation of starch and the formation of sugars during sprouting. This increase can be described as "senescent sweetening" (*16*). In the current study, however, this increase was not observed probably because the storage time was not long enough to observe this phenomenon. The crude protein content and total free amino acid content remained constant in time because sprouting was not initiated yet. Sprouting is associated with a decrease in the crude protein content (*17*).

The reducing sugar content of potatoes depends upon the genetic specification of a particular tuber. On the other hand, however, several other factors, including genotype, environmental conditions, cultural practices during growth, and several postharvest factors including storage, are of high importance as well (*20*). Therefore, it is very difficult to compare the reducing sugar content of every individual variety with those reported in the literature. A relative comparison of varieties on the basis of these reducing sugar contents is however possible. Amrein et al. (*8*) reported lower reducing sugar concentrations for the variety Lady Claire compared to the variety Bintje. Feltran et al. (*18*) observed higher reducing sugar concentrations in the variety Asterix than in the variety Bintje. Similar observations were made in this study. Varieties used for the

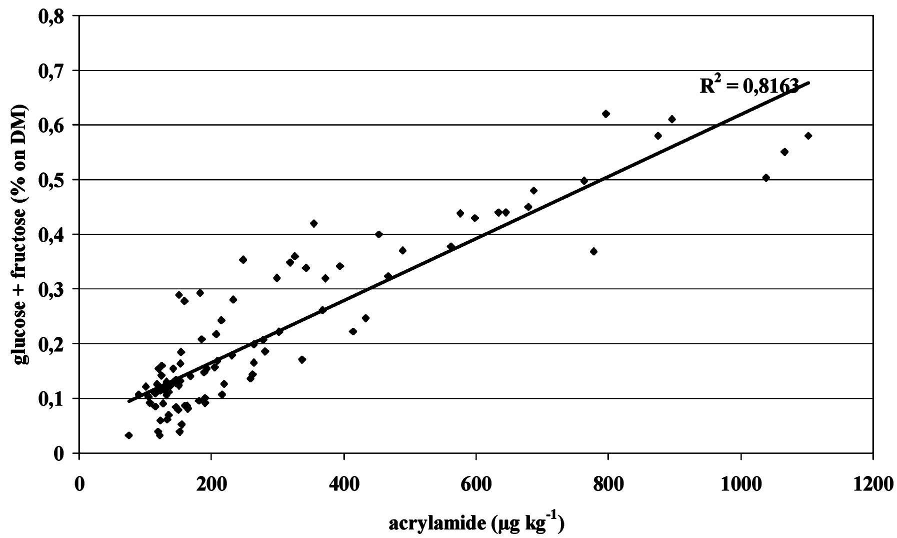

Figure 1. Acrylamide concentration as a function of the reducing sugar content in the potato tuber.

production of potato chips (Saturna, Jupiter, Lady Jo, and Lady Claire) were generally low in reducing sugars. It is well-known that such varieties are bred and selected for their low sugar content.

No significant differences could be detected in the reducing sugar, sucrose, crude protein, total free amino acid, and asparagine content in potatoes grown on two different types of soil. The soil type could have an influence on the reducing sugar concentration through the amount of soil moisture present. It should be noted however that there are conflicting opinions about the role of soil moisture on sugar accumulation in potatoes (*21*). In this study, it could be possible that the difference in moisture content was not big enough to induce significant differences in the reducing sugar content. Moreover, fertilization of the soil could have an important influence on the reducing sugar concentration, but in this investigation, the fertilization level was similar for both soil types. The only parameter influenced by the type of soil is the DM content. The DM content was significantly higher in tubers grown on a sandy loam soil. This is in accordance with the results of Burton (*16*), which confirms that the DM content is related to the water availability of the soil.

Influence of the Tuber Size and Underwater Weight of the Tuber on the Chemical Composition of the Potato. In the industrial process, the first step in storage is grading. Potatoes that are <50 mm are eliminated. Potatoes that are >50 mm are used in the French fry production. The DM, fructose, glucose, and sucrose contents were significantly different between two tuber sizes. Smaller tubers were richer in reducing sugars and sucrose. This is a confirmation of the results of Misra and Chand (*22*) and Nelson and Sowokinos (*23*) and is related to the maturity of the tuber. During maturation, nutrients are transported from the leaves to the tuber, which causes an increase in DM. The sugar content in immature potatoes is higher because the degree of translocation of sugars from the leaves to the tuber exceeds the degree of transformation of sugars to starch.

It is important to separate potatoes into groups of different underwater weight for purposes of more uniform mealiness, yields of processed product, and quality of the finished product. An underwater weight of 380−420 g 5 kg^{-1} is optimal for French fry processing. A low underwater weight causes French fries that are too weak, too wet, or absorb too much oil. Too high of values can yield French fries that are too hard and dry. A decrease in the reducing sugar content was observed with an increasing underwater weight. According to Iritani (*24*), a minimum in the reducing sugar content coincides with a maximum of DM. This is again related to the maturity of the potato. A mature potato has a high underwater weight and thus a lower reducing sugar content.

Acrylamide. In the previous section, the influence of variety, soil type, storage time, tuber size, and underwater weight on the chemical composition of raw potatoes was studied. French fries of the different tubers were prepared, and the acrylamide content was determined and evaluated to correlate these data with the previous observations on the tuber composition.

Influence of Storage Time, Variety, and Type of Soil on Acrylamide Formation. Concerning storage time, the acrylamide formation did not change significantly over 8 months of storage for all of the varieties (results not shown). This is in accordance with the previous results from De Wilde et al. (*11*). The general trend in acrylamide formation during frying of potatoes is that the reducing sugar content determines the acrylamide formation (*8*−*11*). Thus, changes in acrylamide formation will mostly correlate with changes in the reducing sugar concentration.

During the evaluation of the acrylamide formation after frying of the different varieties, it could be stated that the five crisp varieties were all present in the group with the lowest acrylamide concentration. It should be noted however that these crisp varieties, which are usually not used in the French fry production (because of their typical round form), are fried as French fries. Therefore, it seems important to mention that, if these varieties were prepared as crisps, the acrylamide formation would be much higher because of a larger exposure surface to the heating medium and because of a lower inner mass (*25*). From all of the varieties, it seemed most appropriate to choose varieties with the lowest potential for acrylamide formation. Therefore, varieties such as Tebina, Asterix, and Quincy should be avoided during frying.

It appears that tubers grown on one type of soil did not have a higher potential for acrylamide formation. The influence of soil type in this study appeared to be minimal. This is in accordance with the previous results of the chemical composition of the tubers, where the reducing sugars were unaffected by the type of soil. In contrast, however, significant differences in the acrylamide formation were observed for varieties Asterix, Florida, Fontane, Hommage, and Quincy. Remarkably as well, this significant difference between tubers cultivated on two different soil types was not reflected in their reducing sugar content. No explanation could be found for this deviating behavior. However, there is no indication that one particular soil always gives rise to potatoes that are more prone to acrylamide generation during frying.

Finally, all measured parameters were evaluated for a correlation with the acrylamide formation. A good correlation ($R^2 = 0.82$, $n = 96$) between the reducing sugar concentration and the acrylamide formation was obtained (**Figure 1**). This was also observed in other studies (*8−11*) and confirms our previous results (*11*). All other parameters correlated poorly with the potential of acrylamide formation: DM content ($R^2 = 0.0086$, $n = 96$), crude protein content ($R^2 = 0.1548$, $n = 96$), total free amino acid content ($R^2 = 0.0102$, $n = 96$), sucrose ($R^2 = 0.0036$, $n = 96$), and asparagine content ($R^2 = 0.0406$, $n = 96$). Nonetheless, this does not mean that there are no other precursors available for acrylamide formation (*26*, *27*).

From these results, selection of the appropriate variety seems of extreme importance to control acrylamide formation during frying. Because acrylamide formation is strongly correlated with the amount of reducing sugars present in the raw material, it could be useful to screen potato varieties primarily on their reducing sugar contents to select the varieties suitable for frying. Moreover, fresh potatoes sold in retail should be labeled clearly that they are suitable for frying, because potatoes used for other applications are often stored at low temperatures to suppress sprouting. This low-temperature storage is very detrimental for acrylamide formation (*11*, *28*).

Influence of the Tuber Size and Underwater Weight of the Tuber on Acrylamide Formation. Smaller tubers are more susceptible to acrylamide formation than larger tubers. Thus, it can be concluded that size selection will minimize acrylamide formation drastically. It is very important that this size selection will be carried out at the industrial level as well as in the fresh market for potatoes sold for home frying.

The underwater weight of the tuber had a minor, not significant influence on the acrylamide formation. Although the reducing sugar generation during frying was influenced to some extent by the underwater weight, the acrylamide concentrations remained constant. It could be possible that the differences observed in the reducing sugar concentration were too small or that a threshold value needed to be achieved to induce significant differences in the acrylamide formation. The variation occurring in the reducing sugar concentration appeared to be minor; therefore, no changes in the acrylamide concentration were noticed.

ABBREVIATIONS USED

DM, dry matter.

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