Lactic Acid Fermentation Reduces Acrylamide Formation and Other Maillard Reactions in French Fries

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ABSTRACT: Blanched and nonblanched potato rods (var. Beate) were fermented with *Lactobacillus plantarum* strain NC8 (10^9 colony-forming units [CFU]/mL) at 37 °C for 45 and 120 min. Potato rods were pre-fried at 170 °C for 3 min, cooled, and subsequently deep-fried for 2 min 15 s. Potato juice (var. Beate) was fermented with the same strain (10^8 CFU/mL) at 30 °C for 1 to 5 h. Lactic acid fermentation of nonblanched potato rods for 45 min reduced acrylamide level in French fries with 48%, and with 71% after 120 min. By blanching potato rods before fermentation, reductions in acrylamide after 45 min and 120 min were 79% and 94%, respectively. Blanching, and especially fermentation, reduced visually judged browning of the French fries. Fermentation of potato juice reduced pH from 5.70 to 4.05 after 3 h. Simultaneously, glucose declined from 610.8 mg/100 mL to 7.9 mg/100 mL, fructose from 457.8 mg/100 mL to 0.0 mg/100 mL, and sucrose from 132.0 mg/100 mL to 29.2 mg/100 mL. Asparagine content remained largely unaffected between 0 h (1217.5 μmol/100 mL) and 4 h (1175.6 μmol/100 mL) and increased slightly (1470.3 μmol/100 mL) after 5 h fermentation. Levels of several other amino acids involved in Maillard reactions, that is, alanine, arginine, phenylalanine, and serine, decreased during fermentation. It is concluded that acrylamide formation during production of French fries can be effectively lowered by lactic acid fermentation of potato rods before deep-frying. The reduction is due to reduced levels of reducing sugars rather than reduction of available asparagine.

Keywords: acrylamide, *Lactobacillus plantarum* NC8, French fries, reducing sugars, amino acids

Introduction

Acrylamide and other Maillard products are formed at high food processing temperatures (Mottram and others 2002; Stadler and others 2002). Many of the reaction products formed are visible to the naked eye as brown coloration of products that are fried or oven-baked, such as crisp bread, processed potato products, cookies, and coffee (Svensson and others 2003). One of the major routes for acrylamide formation is the reaction between asparagine and the carbonyl group of a reducing sugar such as fructose or glucose (Mottram and others 2002; Yaylayan and others 2003; Zyzak and others 2003; Taeymans and others 2004).

Acrylamide is known to be a neurotoxic, genome-affecting, and carcinogenic compound (Friedman 2003; Dybing and others 2005). The long-term effects of acrylamide are not yet fully understood. Still, the food industry has recently devoted great attention to understand the chemistry of the compound, to improve the analytical methods, as well as to modify the processing conditions to reduce formation of acrylamide in food commodities (Taeymans and others 2004). Because of the discovery of acrylamide in food in 2002, the Food and Drug Administration (FDA) has initiated a broad range of activities on acrylamide, including being at the forefront of new toxicology research on acrylamide. The results from these studies are expected in 2007. Until then, the FAO/WHO expert committee on Food Additives in February 2005 (JECFA/64/SC) recommended that the efforts toward reduced acrylamide concentrations in food should continue.

Food processing approaches to reduce the amount of acrylamide formed could be directed toward reducing the amount of reactants, that is, asparagine and reducing sugars, and/or making conditions for the reaction unfavorable. Thus, blanching of potatoes before frying, lowering pH, and increasing moisture have been shown to reduce acrylamide levels (Jung and others 2003; Kita and others 2004; Pedreschi and others 2005).

Lactic acid bacteria convert reducing sugars in vegetables to lactic acid thus lowering pH (Slinde and others 1993; Kaaber and others 1995). Previous studies have shown that lactic acid fermentation of potato (Kaaber and others 1995) and carrot slices (Slinde and others 1993; Baardseth and others 1995, 1996) reduces sugar levels, amounts of Maillard products, and the burnt taste of deep-fried chips. Preliminary unpublished experiments with deep-fried potato and carrot chips in our lab have shown that fermentation of the slices with *Lactobacillus plantarum* NC8 may lower acrylamide formation in the final product. However, to the authors' knowledge, no previous study has been published on the effect of lactic acid fermentation on acrylamide contents in heat-processed potato products.

The aim of the present study was to investigate the potential of lactic acid fermentation of potato rods before deep-frying as an industrial process for reducing acrylamide formation and brown color development in French fries during deep-frying. A further purpose was to investigate whether a reduction in acrylamide was due to reduced levels of sugars alone or if the selected *L. plantarum* strain also metabolizes asparagine and other amino acids during the fermentation process.

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Materials and Methods

Bacterial inoculum

Lactobacillus plantarum strain NC8, a stable plasmid free strain (Shrago and others 1986; Aukrust and Blom 1992), was grown at 37 °C overnight in (MRS) (DIFCO, Detroit, Michigan, U.S.A.), medium and harvested at a maximum density of 10^9 colony-forming units (CFU)/mL. The cells were centrifuged at 4000 × *g* for 10 min in a HERAEUS 4KR, using the 1000-mL buckets (Thermo Electron Corp., Boston, Mass., U.S.A.). The pellet was dissolved in water at 37 °C to 10^9 CFU/mL before addition to potato rods or juice.

Blanching and fermentation of potato rods

Potatoes (var. Beate) were obtained from a local grocery store. The potatoes were peeled (abrasive peeling C12P, Machinefabriek Eillert B.V., Ulft, The Nederland) and cut into 9 × 9 mm rods (Coupe-Frites, Bron-Coucke S.A., Orcier, France). The rods were kept in water until further treatment. One batch of potato rods was used directly for fermentation, while another was blanched in water at 80 °C for 5 min and cooled in water before fermentation. Fermentation was performed with 1-kg potato rods in 2-L jars together with 1 L cell inoculum at 10^9 CFU/mL. The rods were incubated at 37 °C and samples were withdrawn after 45 and 120 min of fermentation, dried by shaking, and immediately deep-fried. Control samples were deep-fried without delay after peeling and cutting.

Two parallel portions of 200-g each were deep-fried in palm oil (Denofa AS, Fredrikstad, Norway) at 170 °C in a Nuova Elframo, Model EB (Bergamo, Italy) fryer. The frying regime was as followed: deep-fried (pre-frying) for 3 min, cooling in air for 5 min followed by a 2nd deep-frying for 2 min 15 s. Samples were photographed and duplicate samples analyzed for acrylamide.

Extraction and fermentation of potato juice

Peeled potatoes (var. Beate) were processed into juice in a Braun Multipress type 4290 (Braun GmbH, Kronberg, Germany). The juice was decanted and stored at –25 °C until the start of the experiments. Following thawing at room temperature, the juice (90 mL) was inoculated with 10 mL *L. plantarum* NC8 (10^9 CFU/mL), giving an initial bacterial density of 10^8 CFU/mL. The mixture was incubated at 30 °C and samples withdrawn immediately and then every hour for 5 h. Samples were frozen immediately and stored frozen until they were analyzed for pH, sugars, and free amino acids. The experiment was performed in duplicate with separate tubes for each sampling.

Acrylamide

Acrylamide was analyzed using solid-phase extraction before liquid chromatography/mass spectrometry as described by Young and others (2004).

The homogenization step was slightly modified as 5 g homogenized sample was diluted to 100 mL with water, vigorously shaken for 30 min, and adjusted to pH 7 to 9 by 0.5 *M* NaOH. The mixture was filtered through glass-fiber by suction, before aliquots were applied on the preconditioned SPE columns. The final analysis is done by reversed-phase LC and detected by MS, identified by 2 ion fragments.

pH

Duplicate samples of potato juice were carefully thawed on ice and pH was measured immediately using a WTW pH 340 meter (WTW Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) equipped with a Hamilton Polilyte Lab electrode (HAMILTON Bonaduz AG, Bonaduz, Switzerland) and a WTW TFK 325 temperature sensor. Calibration was performed with Hamilton DURACAL™ pH buffers.

Sugars

Sucrose, glucose, and fructose were determined by high-performance liquid chromatography (HPLC) using a Hewlett Packard 1100 Series chromatography system (Agilent Technologies, Inc., Palo Alto, Calif., U.S.A.) and a Gilson 132 refractive index detector (Gilson Medical Electronics Inc., Middleton, Wis., U.S.A.). The chromatographic system was equipped with a Chrompack Carbohydrates Pb (5 μm) 300 × 7.8-mm inner dia analytical column and a pre-column containing the same material (Varian, Inc., Palo Alto, Calif., U.S.A.). The mobile phase was water, and the system was operated at 80 °C at a flow of 0.4 mL/min. Sucrose, glucose, and fructose (Chem Service, West Chester, Pa., U.S.A.) were used as external standards.

Potato juice samples were diluted (1:1 w/w) with ethanol, kept at 65 °C for 60 min, and passed through C-18 SepPack cartridges, which had previously been activated by 2 mL methanol and 5 mL deionized water (Bach Knudsen 1997). One mL of the eluents was dried on a heating block until ethanol was evaporated. Samples were diluted to proper volume by water and injected onto the chromatograph.

Free amino acids

The free amino acids in the potato juices were analyzed by ion exchange chromatography on a Lithium High Performance Column (Biochrom Ltd., Cambridge, U.K.) in an automated amino acid analyzer (Biochrom 20, Biochrom Ltd.), using lithium-based eluents and post-column derivatization with ninhydrin (Physiological Fluid Chemical Kit, Biochrom Ltd). Data were analyzed against external standards (Sigma amino acid standard solutions: acidics, neutrals, and basics, supplemented with glutamine, all purchased from Sigma Chemical, St. Louis, Mo., U.S.A.) using the Chromeleon® Chromatography Management Software (Dionex Ltd., Surrey, U.K.). Duplicate samples (2 × 1 mL) of the potato juices were centrifuged at 16000 × *g* for 15 min at 4 °C (Biofuge Fresco, Heraeus Instruments, Kendro Laboratory Products GmbH, Hanau, Germany). Of the supernatants, 50 μL were diluted with 450 μL 0.2M lithium citrate loading buffer, pH 2.2 (Biochrom Ltd.) and microfiltrated (0.2 μm Spartan membrane filter, Schleicher & Schuell, Dassel, Germany) before injection (20 μL).

Calculations and statistical analysis

Significant ($P \leq 0.05$) differences among means of each sugar and amino acid were ranked using the Ryan-Einot-Gabriel-Welsch multiple F test (REGWQ) through the MEANS statement in the PROC GLM procedures of SAS (SAS Inst. 1990).

Results and Discussion

Blanching and fermentation of potato rods

Both blanching and lactic acid fermentation of potato rods before deep-frying significantly reduced acrylamide formation during the production of the French fries (Figure 1).

The fermentation of nonblanched potato rods reduced acrylamide contents in the French fries with 48% and 71% after 45 min and 120 min of fermentation, respectively. The combined effects of blanching and fermentation amounted to a decline in acrylamide formation of 79% after 45 min of fermentation and 94% when fermentation continued for 120 min.

The acrylamide level of 2400 μg/kg found in the present study in the French fries produced from potato rods not subjected to

Table 1—Effects of lactic acid fermentation on pH and concentrations of sugars and free amino acids in potato juice

		Fermentation period at 30 °C						
		0 h[a]	1 h	2 h	3 h	4 h	5 h	S.E.M[b]
pH		5.70a[c]	4.78b	4.19c	4.05d	3.93e	4.06d	0.0
Sugars (mg/100 mL)								
Sucrose		132.0ab	298.9a	174.7ab	29.2b	1.4b	2.4b	67.45
Glucose		610.8a	10.6b	12.4b	7.9b	0.0b	0.0b	5.92
Fructose		457.8a	77.1b	17.3b	0.0b	0.0b	0.0b	25.77
Free amino acids (μmol/100 mL)								
Alanine	ala	225.9a	222.7a	169.9b	147.9c	142.7c	101.4d	1.72
Arginine	arg	284.1a	223.2b	224.0b	224.9b	198.2c	148.4d	1.17
Asparagine	asn	1217.5bc	1233.7b	1214.6bcd	1161.4d	1175.6cd	1470.3a	9.67
Aspartic acid	asp	256.7a	261.2a	225.7b	211.9c	204.4c	172.8d	1.82
γ-aminobutyric acid	gaba	617.3b	676.4a	662.6a	657.1a	647.2ab	412.5c	6.71
Glutamic acid	glu	55.7f	90.2e	125.4d	141.1c	147.5b	174.4a	0.88
Glutamine	gln	1253.9c	1351.3b	1275.9c	1192.4d	1187.0d	1455.1a	9.42
Glycine	gly	84.1a	86.0a	76.0b	64.7c	67.4c	58.5d	1.00
Histidine	his	40.1a	41.2a	39.4a	35.9b	35.4b	27.8c	0.36
Isoleucine	ile	129.0a	133.4a	121.2b	108.9c	104.2c	48.4d	0.98
Leucine	leu	66.7a	61.3b	52.4c	40.1e	43.4d	24.9f	0.24
Lysine	lys	114.8ab	121.3a	114.4ab	111.8b	110.5b	85.5c	1.33
Methionine	met	92.9a	96.3a	86.7b	83.6bc	79.7c	55.4d	0.95
Phenylalanine	phe	86.3b	88.7a	74.5c	64.6d	57.9e	23.9f	0.34
Proline	pro	58.6b	62.5a	55.4b	45.7c	40.6d	36.3e	0.66
Serine	ser	123.5a	102.4b	75.9c	43.8d	40.1e	21.0f	0.61
Threonine	thr	198.9b	207.9a	195.1b	173.3c	179.1c	136.8d	1.65
Tyrosine	tyr	19.3b	22.0a	17.2c	11.4d	9.9e	2.4f	0.10
Valine	val	324.0a	332.5a	308.0b	287.6c	275.8c	185.6d	3.15
Total free AA[d]	FAA	5249b	5414a	5114c	4808d	4747de	4641e	23.6

[a]Incubation time (h) after the addition of *Lactobacillus plantarum* NC8 (10^8 colony-forming units [CFU]/mL potato juice).
[b]Pooled standard error of mean (S.E.M).
[c]Means within each treatment (row) with different letters are different ($P \leq 0.05$).
[d]Sum of all analyzed free amino acids (cysteine was not detected).

blanching or fermentation (Table 1), is well within ranges reported previously. Thus, Lingnert and others (2002) indicated that 300 to 700 μg/kg is the typical acrylamide range for French fries with 3500 μg/kg as an upper extreme value, whereas Jung and others (2003) reported about 1500 μg/kg and Friedman (2003) found values between 200 and 12000 μg/kg.

Blanching of potato rods has previously been shown to reduce acrylamide formation in French fries. Grob and others (2003) reported about 50% reduction in acrylamide level of French fries after blanching of the potato rods before deep-frying. Similar reductions were reported after blanching potato slices before deep-frying into potato chips (Pedreschi and others 2005).

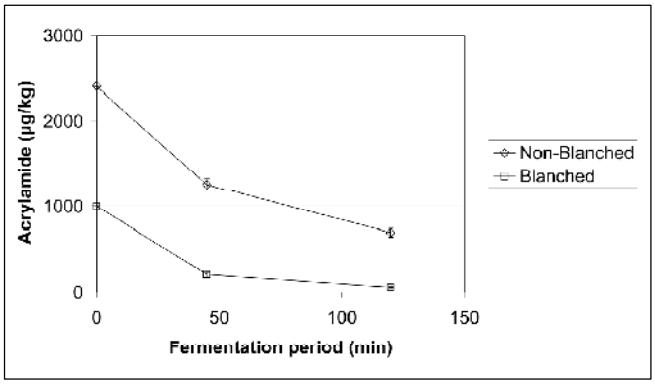

Figure 1—Reduction of acrylamide formation in French fries as a function of time of fermenting blanched and nonblanched potato rods with *Lactobacillus plantarum* NC8 (10^9 colony-forming units [CFU]/mL) before deep-frying. Bars show standard deviation of duplicate experiments

The fermentation process had a pronounced effect on the color of the French fries as the color turned lighter and less brown when the potato rods were fermented before frying (Figure 2). The lightness increased with the extension of the fermentation period. Blanching was also efficient in reducing brown color of the French fries. Even further improvement in color of the French fries was achieved when the blanched potato rods were fermented before deep-frying.

Sensory analysis of the French fries was not carried out in the present study. However, although pH was reduced and sugar levels declined during fermentation, there was no distinguishable taste difference between the fermented French fries and the unfermented control. In a limited consumer test no comments were given with regard to difference in taste, but a preference for the light colored fries was expressed. In a previous study it was shown that fermentation of carrots induced a fresh, slightly sour taste to carrot chips (Slinde and others 1993). In French fries, lowering of pH by dipping in 1% citric acid for 1 h before frying caused no detectable taste difference compared with the control, whereas dipping in 2% citric acid promoted a slightly sour taste and harder texture (Jung and others 2003).

Pedreschi and others (2005) reported a lighter color in blanched, deep-fried potato slices than in nonblanched slices. Lactic acid fermentation of potato slices has previously been shown to increase lightness in deep-fried potato chips (Kaaber and others 1995). In the latter study, the change in color caused by the fermentation process was shown by instrumental color analysis (increased L^* values in the $L^*a^*b^*$ color system) as well as by visual judgments. The color of deep-fried potato products arises from the non-enzy-

matic Maillard browning reaction, involving sugars and amino acids on the surface of the potato, with reducing sugars being the limiting factor (Marquez and Añón 1986). Pedreschi and others (2005) reported a linear correlation between acrylamide content of the potato chips and their color represented by the redness component a^* in a given temperature range (120 °C to 180 °C). With the mechanisms revealed for acrylamide formation, that is, reactions between a reducing sugar and asparagine (Yaylayan and others 2003; Zyzak and others 2003), the industry's efforts to produce light-colored potato products coincide with their requirements for producing products low in acrylamide (Becalski and others 2004). However, browning level is not a reliable measure of acrylamide content in large-surface fried potato products (Taubert and others 2004).

Several strategies have been suggested for keeping reducing sugars in the raw material at low levels, that is, selection of suitable potato varieties (Amrein and others 2003; Matthäus and others 2004; Olsson and others 2004; Williams 2005), optimizing storage regimens to prevent cold-induced production of reducing sugar (Noti and others 2003; Matthäus and others 2004) and blanching to wash out sugars before deep-frying (Grob and others 2003; Kita and others 2004; Pedreschi and others 2004). Furthermore, reducing the pH by soaking in acids resulted in a lower rate of Maillard browning (Slinde and others 1993; Aukrust and others 1995) and acrylamide formation (Jung and others 2003; Kita and others 2004; Weisshaar 2004). Modifying deep-frying conditions (Becalski and others 2003; Granda and others 2004) and optical sorting to remove dark products (Taeyemans and others 2005) have also been advocated.

Extraction and fermentation of potato juice

It is well known that *Lactobacilli* metabolize glucose and fructose, and we have previously shown that these sugars are also metabolized during lactic acid fermentation of potato (Kaaber and others 1995) and carrot (Slinde and others 1993) slices. The bacterial removal of sugars will be limited to the outer layers of the vegetable material, and the total amount of sugars metabolized will depend on the surface-to-volume ratio of potato slices or rods. We therefore chose potato juice as a model for studying sugar and amino acid levels during lactic acid fermentation of the raw material.

Levels of reducing sugars in the potato juice

Lactic acid fermentation of potato juice reduced pH from 5.70 to 4.19 after 2 h of fermentation and further to 4.05 after fermenting for 3 h, where it remained stable for the rest of the experimental period (Table 1). The initial sugar levels of the potato juice used in the present study were comparable, although in the upper range, of levels previously reported for potatoes (Kaaber and others 1995; Becalski and others 2004; Kita and others 2004; Williams 2005). A decrease in sucrose concentration occurred after 3 h of fermentation. The numerical, but statistically not significant, increase in sucrose during the 1st h of fermentation (Table 1) may have been caused by endogenous invertase activity, which might have hydrolyzed sucrose during preparation of the nonfermented potato juice before the sugar analysis. The contents of glucose and fructose were greatly reduced already after the 1st h of fermentation, and no monosaccharides were detectable in the juice after 4 to 5 h of fermentation.

Kaaber and others (1995) obtained reductions in total sugar contents in slices from various potato varieties between 72% and 96% after fermentation for 24 h at 23 °C with *Lactobacillus* strain NCIMB 40450 at an inoculum level of 10^7 CFU/mL. The present reduction of 97% of total sugars within 3 h of fermentation (Table 1) demonstrates the importance of selecting an efficient bacterial strain, high inoculum density, and optimal temperature for the effectiveness of bacterial degradation of sugars.

Levels of free amino acids in the potato juice

There were considerable changes in the levels of free amino acids (FAA) in the potato juice after lactic acid fermentation (Table 1). Initially, a 3% net increase ($P < 0.05$) in the total amount of FAA was observed after 1 h of fermentation. This might be due to both en-

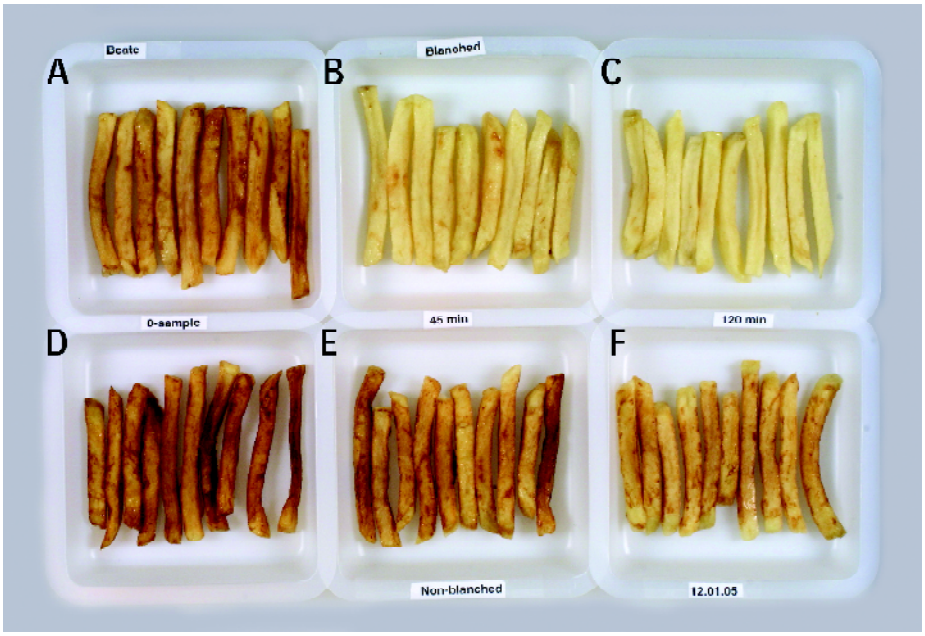

Figure 2—Browning in blanched and non-blanched, fermented and unfermented, deep-fried French-fries. A and D = unfermented (A = blanched, D = nonblanched); B and C = blanched and fermented for 45 and 120 min; E and F = nonblanched and fermented for 45 and 120 min.

dogenous protease activity in the potato juice and lysis of some of the bacterial cells added at the start of incubation. However, samples collected at later stages during fermentation (2 to 5 h) showed a decrease ($P < 0.05$) in FAA compared with the amounts before fermentation. The *Lactobacilli* fermentation of AA in potato slices or rods will be limited to the outer layers of the vegetable material, thus the total amount of protein/AA metabolized will have a minor effect on the nutritional quality of the nitrogenous nutrients in the final product. The 2 most abundant amino acids present in free form in all samples were the amides asparagine and glutamine (approximately 25% and 30% of total FAA, respectively). This is in accordance with earlier findings (Brierley and others 1996; Amrein and others 2004; Olsson and others 2004).

In the present study, all amino acids except glutamic acid, asparagines, and glutamine showed a marked decrease ($P < 0.05$) during the 5 h of fermentation. The most prominent decrease was observed in the concentrations of isoleucine, leucine, phenylalanine, serine, and tyrosine (ranging from 63% to 87% reduction, compared with initial values). When growing *L. plantarum* in culture, valine, isoleucine, leucine, tyrosine, and phenylalanine were consumed mainly as free amino acids, whereas asparagine, proline, lysine, and arginine were mainly derived from peptides (Kask and others 1999). In addition, several FAA (asparagine, serine, glutamic acid, valine, isoleucine, leucine, phenylalanine) were consumed in higher amounts than needed to build up cell protein (Kask and others 1999). For growth of *L. plantarum* NC8 in culture, arginine, leucine, isoleucine, tyrosine, and valine were essential, whereas asparagine was not (Møretrø and others 1998). Some proteolytic activities are associated with growth of *L. plantarum* NC8, as milk is clotted after 12 h at 20 °C with a 10^6 CFU/mL inoculum (Holck and Næs 1992). Upon fermenting potato rods, this may influence proteins on the surface of the potato rods and provide amino acids for use in growth. The practical implementation of this must, however, be judged from the knowledge that the free amino acids present in the potato covers ample concentrations of all amino acids essential for growth of *L. plantarum* NC8 (Arg, Leu, Ileu, Tyr, and Val) (Møretrø and others 1998).

In the present experiment, we added a high number of bacteria (10^8 CFU/mL) to the potato juice, thus only a small increase in cell number (up to 10^9 CFU/mL) is to be expected. However, even this near to steady-state condition requires amino acids for growth and maintenance.

When comparing our results of changes in the FAA concentrations in the potato juice during the fermentation with *L. plantarum* NC8, with the amino acid composition of the *L. plantarum* biomass reported by Kask and others (1999), it seems that the *L. plantarum* NC8 strain consumed more arginine, serine, phenylalanine, methionine, isoleucine, valine, leucine, tyrosine, glx (glutamic acid [glu] + glutamine [gln]) and asx (aspartic acid [asp] + asparagine [asn]), and less lysine, proline, glycine, histidine, and threonine than needed to build up cell protein. Between 4 and 5 h of fermentation, the concentrations of asparagine and glutamine increased ($P < 0.05$) by approximately 24%, whereas the concentration of γ-aminobutyric acid was reduced ($P < 0.05$) by 36%. Simultaneously, the pH of the potato juice (Table 1) also showed an increase ($P < 0.05$). This might be a result of the bacterial cells trying to compensate and adjust to the nonphysiological low pH values (<4) and also possibly due to increased hydrolysis of peptides/proteins in the potato juice. *Lactobacilli* have been shown to possess a specific antiport for glutamate/γ-aminobutyric acid (Higuchi and others 1997; Cotter and Hill 2003). It is not known, however, whether the antiport can reverse this transport across the cellular membrane. It is worth bearing in mind, however, that as the pH in the potato juice decreases (that is, due to the fermentation and release of lactic acid), the free amino groups become protonated and some FAA (that is, serine, valine, and isoleucine) are less stable at lower pH values.

It is well established that acrylamide is formed from asparagine and reducing sugars like glucose and fructose by the Maillard reaction occurring at high temperatures (Mottram and others 2002; Stadler and others 2002). Fructose may be more reactive in acrylamide formation than glucose (Becalski and others 2004). The rearrangement and degradation of a Schiff base to acrylamide is at present not fully understood and neither is the kinetics of the reaction between carbonyl and asparagine (Taeymans and others 2004). Furthermore, the key intermediates of the reaction remains to be elucidated (Dybing and others 2005). In the 1st experiment of the present study, we showed that including a lactic acid fermentation step before the deep-frying of French fries could reduce acrylamide formation. In the 2nd experiment, we revealed that the concentration of both glucose and fructose declined rapidly during lactic acid fermentation, whereas asparagine contents remained largely unaffected during the 1st h after incubation. This indicates that reducing sugar is a key rate-limiting factor for acrylamide formation in fried potato products such as French fries. This is in agreement with the recent studies by Amrein and others (2004), revealing that acrylamide formation in potato tubers was mainly determined by the contents of glucose and fructose and not by the content of asparagine. Conversely, Zyzak and others (2003) and Becalski and others (2004) found that the level of asparagine affected content of acrylamide in certain potato products. *Lactobacillus plantarum* NC8 shows no asparaginase activity, although other *Lactobacillus* species are capable of hydrolyzing asparagine to aspartic acid (Møretrø and others 1998).

The decreased levels of reducing sugars most likely caused the observed reduction in thermal browning during deep-frying of potato rods. The fermentation also caused substantial reduction in levels of some of the amino acids shown to be involved in model Maillard reactions, especially alanine, arginine, phenylalanine, and serine (Ajandouz and Puigserver 1999; Kwak and Lim 2004). There were only small changes in lysine content during the 1st 3 to 4 h of fermentation, and lysine is known to be the most reactive amino acid in Maillard reactions (Adrian 1974).

Conclusions

Acrylamide formation during production of French fries can be efficiently lowered by lactic acid fermentation of the potato rods before deep-frying. The reduction in the formation of acrylamide by fermenting the potato rods with *L. plantarum* NC8 before deep-frying is due to reduction in the levels of reducing sugar rather than a specific reduction in the levels of available asparagine. Lactic acid fermentation also reduces formation of Maillard products clearly visible as reduced brown color of the French fries.

Acknowledgments

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