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Research Article

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Vacuum impregnation pre-treatment: A novel method for incorporating mono- and divalent cations into potato strips to reduce the acrylamide formation in French fries

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Abstract: The effect of different vacuum impregnation (VI) pre-treatments of potato strips [in water (control), NaCl, KCl or $CaCl_2$ (0.1 M) for 10 and 15 min] on acrylamide formation in French fries after deep frying in sunflower oil at 175°C for 5 min was determined. The acrylamide content of fries prepared with potato strips pretreated by VI in distilled water decreased from 0.82 to 0.24 µg/g when time increased to 15 min. Moreover, the acrylamide content of fries from 10 min-KCl pre-treatment (0.35 µg/g) decreased significantly to 0.04 µg/g when time was 15 min ($p < 0.05$). In comparison to control (10 min), the VI pre-treatment in KCl and NaCl for 15 min reduced the relative content of acrylamide by 95 and 91%, respectively, and VI in distilled water was able to decrease this value by 71%. Results indicated that monovalent cations (K and Na) were more effective in reducing acrylamide formation than divalent cation (Ca^{2+}) when the VI pre-treatment time increased to 15 min. In conclusion, VI as a pre-treatment for mono- and divalent cations in fried potato production could be a useful technique in industrial applications to reduce acrylamide formation in fries in a short time.

Keywords: acrylamide, vacuum, potatoes, frying, vacuum impregnation

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1 Introduction

Acrylamide formation routes via Maillard reactions between reducing sugars like glucose and fructose and amino acids like asparagine when foods are exposed to temperatures above 120°C [1,2]. The acrylamide formation in foods is influenced by various parameters such as temperature and time, pH value of a reaction medium and water activity, which may affect the rate of these reactions [3,4]. Acrylamide contents in heat-treated potato-based products can be high, especially in potato chips and deep-fried potato products [5]. Many heat-treated foods such as toasts, biscuits, crackers, cookies, breakfast cereals, bakery products, roasted nuts, sherbet desserts, popcorn, and roasted coffee may be also high in their acrylamide content [6–8]. The content of acrylamide in deep-fried potatoes has been previously reported in the range of 20–1,000 µg/kg [9]. Acrylamide formation is a serious health problem [10], and studies conducted on experimental animals indicated that it has neurotoxic, carcinogenic, and genotoxic properties and may cause various problems on human genital system [11,12]. In 1994, acrylamide was classified as "a possible carcinogen for humans" by the International Cancer Research Agency and included in Group 2A [13]. For the daily intake of 1 µg acrylamide/kg body weight, the risk of cancer has been calculated between 0.7 and 4.5 per 1,000 [14].

Carbonyl compounds like glucose and fructose and amino acids like asparagine in carbohydrate-rich foods are the major precursors for acrylamide formation via Maillard reactions during thermal processing [15]. Acrylamide formation is closely related with the contents of these precursors in potatoes [16]. The ratio of free asparagine and reducing sugar is higher in potatoes, and the concentration of reducing sugars or asparagine may limit the formation of acrylamide in potato products depending on their chemical composition [17,18]. Most of the methods used to reduce acrylamide formation in foods are aimed to remove these precursors such as glucose, fructose, and asparagine or to prevent or reduce the Maillard reaction with different process modifications. On the other hand, the biggest challenge is to reduce the level of acrylamide in fried potatoes without sacrificing the sensory properties of the end product [19]. According to the data obtained from the studies in the literature, recommendations to food producers and consumers by the Joint Institute for Food Safety and Applied Nutrition in the University of Maryland (College Park, MD, USA) [20] to reduce the acrylamide content in foods include (1) shortening the temperature and time of frying and baking as much as the process allows, to avoid deep-fat frying, (2) adding asparaginase enzyme to reduce the asparagine content, (3) soaking potatoes in warm water to remove asparagine and sugars from the surface and storing potatoes at temperatures below 8°C, (4) adding acids like citric acid into the food formula to lower the pH, (5) preferring yeast fermentation instead of using chemical leavening agents in the production of bakery products, using sodium hydrogen carbonate instead of ammonium hydrogen carbonate, and (6) adding substances like sulfites to reduce the Maillard reactions.

Vacuum impregnation (VI) process is a technology that can accelerate the osmotic dehydration in foods. Osmotic dehydration is a common method used to remove water from plant tissue at certain rates in osmotic solution. This method is a pre-treatment applied to improve the nutritional, sensory, and functional properties and preserve their integrity of fruits and vegetables that are subjected to preservation methods such as freezing, freeze drying, microwave drying, air drying, and vacuum frying [21].

Many strategies are available to reduce acrylamide contents of potato-based foods [15]. One of them is to use mono and divalent cations like Na^+ and Ca^{2+}, which may inhibit the formation of Schiff base and the acrylamide formation since these cations may react with asparagine [22]. Calcium chloride may reduce acrylamide formation by reducing the pH of the medium [23] while divalent cations have been reported to be better than monovalent ions in reducing the acrylamide formation [24,25]. These salts could reduce the heat transfer coefficient by decreasing oil absorption rates during frying, which eventually limits acrylamide formation in foods [26]. Significant decreases in acrylamide contents of fried potato products have been reported by the use of mono- and divalent cations [24,25,27]. In most of these studies, potato slices or strips were immersed in solutions of these salts, which takes some time to incorporate these cations into potato products. VI pre-treatment is considered a fast way of delivering beneficial food constituents into different food matrices. Therefore, in this study, the effectiveness of VI pre-treatment as a fast and alternative method applied to raw potato strips on reducing acrylamide levels in French fries was determined. In this context, raw potato strips were vacuum impregnated in four different solutions including distilled water and solutions of $CaCl_2$, KCl, and NaCl (0.1 M each) for two different times (10 and 15 min) under vacuum (70 kPa). The pre-treated potato strips were deep fried in sunflower oil at 175°C for 5 min, and their acrylamide contents were determined.

2 Materials and methods

2.1 Materials

In this study, raw potatoes and sunflower oil (Altın Ekin, Torku, Konya, Turkey) were purchased from a national market in Burdur (Turkey). $CaCl_2$, KCl, and NaCl (ACS grade) were obtained from Sigma-Aldrich (St. Louis, MO, USA), Emsure (Darmstadt, Germany) and Riedel-de Haën (Seelze, Germany), respectively. A potato slicer (Dinnox TF-K344; Ningbo Topfeng International Co., China) was used to cut potatoes into even strips, and an analytical balance (Shimadzu BL-3200H; Shimadzu Co., Kyoto, Japan) was used for weighing. VI unit included a vacuum pump (TC63vd; DHCL Group, Taipei, Taiwan) and a container (RV-261; Re-Va, Izmir, Turkey) (Figure 1), and a commercial deep frier (Sinbo SDF-3827; Deima A.S., Istanbul, Turkey) was used for frying pre-treated potato strips. A gas chromatography-mass spectrometry (GC-MS) unit (Agilent 7890A GC, 5975 mass detector, 7693B automatic sampler; Agilent Technologies, Santa Clara, CA, USA) was used to determine the acrylamide contents in French fries. A high-pressure liquid chromatography (HPLC) system (Prominence, 20A CBM, CTO-10ASVp column oven, LC20 AT pump, and SIL 20ACHT automatic sampler; Shimadzu Co., Kyoto, Japan) with SPD-M20A photodiode array and RID 20A refractive index detectors was used to determine the asparagine, glucose, and fructose contents of impregnation solutions before and after pre-treatment applications since any mass transfer of these components into impregnations solutions might reduce their contents in pre-treated potato strips, which could have an inhibitory

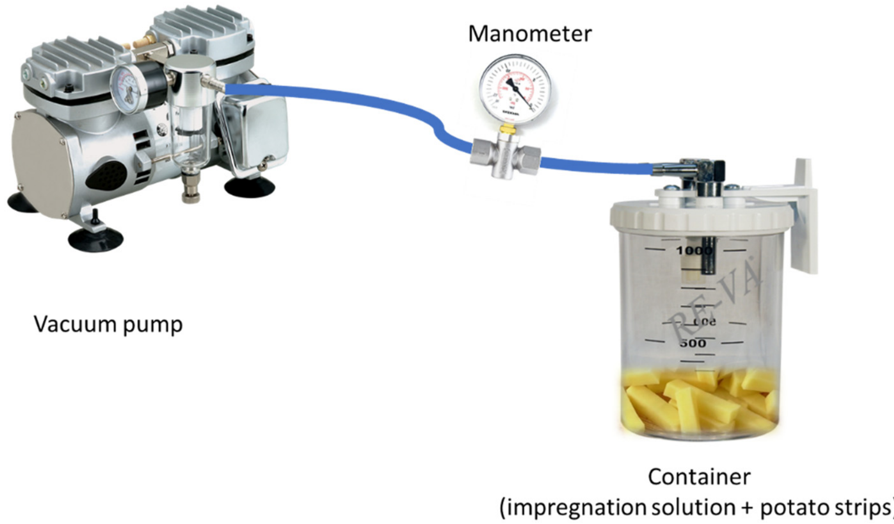

Figure 1: VI unit used in the study and its components.

effect on acrylamide formation in fries. Pure chemicals such as chromatographic grade methanol (Merck, Darmstadt, Germany), fructose and glucose standards (Sigma-Aldrich) were used in analyses.

2.2 Methods

2.2.1 Sample preparation, VI pre-treatments and deep frying

All chemicals were weighed with a precision of 0.1 mg on an analytical balance, and NaCl, $CaCl_2$, and KCl solutions at a concentration of 0.1 M were prepared in volumetric flasks. Raw potatoes were carefully washed and peeled manually and then passed through a slicing machine. Even strips were separated and cut into a standard length (50 mm × 12 mm × 12 mm) by using a sharp stainless-steel knife. Potato strips in similar lengths were randomly divided into three groups representing three replicates, and each replicate contained about 100 g of potato strips. Later, potato strips were exposed to four different VI pre-treatments for 10 and 15 min under 70 kPa vacuum pressure in distilled water or solutions containing 0.1 M NaCl, $CaCl_2$, or KCl (200 mL) at room temperature. Potato strips pre-treated by VI's in distilled water for 10 min were used as a control group to determine the relative reduction rates of acrylamide contents in fries. All experiments were carried out in triplicates. After each experiment, a part of each impregnation solution was taken into a test tube and kept frozen at −24°C prior to glucose, fructose, and asparagine analyses. The pre-treated potato strips were deep fried for 5 min in sunflower oil (2.7 L) in a commercial frier set at 175°C. After French fries were cooled down to room temperature, they were transferred into polyethylene bags and stored at −24°C until acrylamide analyses.

2.2.2 Acrylamide analysis in French fries

In this study, a GC-MS unit was used to determine the acrylamide contents of French fries produced from raw potato strips pre-treated by four different VI solutions. Fries were first homogenized by using a porcelain mortar and a pestle, and then, formic acid solution (10 mL, 0.1%) was added into about 1 g of sample. The mixture was shaken for 20 min on an orbital shaker. The extract was cooled down to 4°C for the removal of oily top layer. Supernatant was filtered through a 0.45 µm syringe filter, and the filtrate was removed and saved prior to a cleaning step. The CarboPrep™ 200 SPE (solid phase extraction) tube (6 mL, 500 mg) was conditioned with acetone (2 mL) and 0.1% formic acid (2 mL). Two milliliters of filtered solution of fried potato extract was applied to the SPE tube. The sample solution was allowed to pass through the tube only by gravity. The SPE tube was washed quickly by passing 0.5–1.0 mL of water through the tube. Vacuum was used for a minute to dry the redundant water in the tube. Then, it was washed with 2 mL of acetone only by gravity. Finally, eluate was prepared for GC-MS analysis [28]. MSDCHEM data system was used to define the peak of acrylamide. Analytes were separated with DB-Wax (30 m × 0.25 mm with a film thickness of 0.2 µm) on a fused silica capillary column. The carrier gas (helium) flow rate was set to 1 mL/min, and oven temperature program included initial temperature 60°C, a minute hold, 20°C rise per minute, temperature increase to 240°C, and a 20 min hold. The injection port, detector, and ion sources temperatures were 240, 250, and 230°C, respectively. The injection volume was 1 μL, and the selective ion monitoring mode ($m/z = 71$) was used [29].

2.2.3 Asparagine analysis in impregnation solutions

For asparagine analysis, each impregnation solution (25 mL) was mixed with HCl acid (0.1 M, 25 mL) and homogenized carefully with a vortex unit (ViseMix, WM-10; Daihan Scientific Co. Ltd, Gang-Won-Do, Korea). This mixture was then centrifuged at 1,649 × *g* at 4°C for 20 min (Allegra X-30R; Beckman Coulter Inc., Indianapolis, IN, USA). Supernatant (1 mL) was mixed with NaOH (2 N, 100 μL), saturated sodium bicarbonate (150 μL), and dansyl chloride (1 mL). This mixture was incubated at 40°C for 45 min and kept at room temperature for 10 min. Fifty microliters of 25% NH_3 was added into this mixture and kept at room temperature for 30 min. Then, 5 mL of ammonium acetate:acetonitrile was added. This mixture was filtered through a 0.45 μm syringe filter and injected directly into the HPLC system [30,31]. The method of Köse et al. [31] was modified and used in the analysis of asparagine by HPLC. The separation of asparagine was achieved on an ACE 5 C18 (4.6 mm × 250 mm, 5 μm) column (Advanced Chromatography Technologies Ltd, Chadds Ford, PA, USA) at 40°C. A photodiode array detector at 254 nm was used to determine the asparagine contents of impregnation solutions.

2.2.4 Glucose and fructose analyses in impregnation solutions

For glucose and fructose analyses, each impregnation solution was filtered through a 0.45 μm syringe filter and injected directly into the HPLC system [32]. Mobile phase was consisted of a mixture of ultrapure water and acetonitrile (20/80, v/v) at a flow rate of 1.0 mL/min, and injection volume was 20 μL. Separations were carried out by an Inertsil NH_2 column (4.6 mm × 250 mm, 5 μm) (GL Sciences Inc., Torrance, CA, USA) at 30°C. A refractive index detector was used to quantify the glucose and fructose contents of each impregnation solution before and after pre-treatments.

2.2.5 Statistical analysis

The SAS System for Windows 9.0 (SAS Institute Inc., Carry, NC, USA) statistical package program was used in statistical analyses. PROC GLM procedure with the Tukey's multiple separation test was used to determine significant differences among means. PROC CORR procedure was used to obtain the Pearson's correlation coefficients. Results were considered statistically significant at $p < 0.05$. Descriptive statistics were presented as mean ± standard deviation.

3 Results and discussion

3.1 Asparagine, fructose, and glucose contents of impregnation solutions

It has been previously reported that immersing in water and/or boiling of potato slices before frying are effective in reducing the formation of acrylamide during frying [26,33,34]. The main purpose of these pre-treatments is to minimize the concentration of acrylamide precursors in potato tubers or to minimize or prevent the occurrence of the Maillard reaction during frying [35–37].

After potato strips had been subjected to VI pre-treatments, asparagine, fructose, and glucose contents of impregnation solutions were monitored since the transfer of these compounds, especially water soluble monosaccharides, from potato strips into impregnation solutions were likely to occur. The contents of these compounds, when distilled water was used as an impregnation solution, are presented in Table 1. VI pre-treatment in distilled water for 10 min resulted in an impregnation solution with an about 1.26 μg/mL asparagine content; however, the asparagine contents of solutions for 10 and 15 min VI applications did not change significantly ($p > 0.05$). Results indicated that part of the asparagine, fructose, and glucose present in potato strips could transfer into distilled water, and their transfer was independent on the duration of pre-treatment ($p > 0.05$). In the present study, the asparagine content of potato strips was not of a major concern but its mass transfer into impregnation solution (i.e. its removal from potato strips) could be as a good indicator for its availability for acrylamide formation during frying. Abou-Zaid [38] reported that soaking potato slices in water before frying had no effect on the

Table 1: Changes in asparagine, fructose, and glucose contents of four different impregnation solutions after the VI pre-treatment of potato strips for two different times

Impregnation solution	Pre-treatment duration (min)	Concentration in impregnation solution* (μg/mL)		
		Asparagine	Fructose	Glucose
Distilled water	10	$1.26 \pm 0.12^{a**}$	10.04 ± 0.08^{e}	9.60 ± 0.80^{d}
	15	1.40 ± 0.09^{a}	10.67 ± 0.09^{e}	33.70 ± 0.71^{d}
NaCl (0.1 M)	10	1.04 ± 0.10^{a}	143.30 ± 4.53^{a}	1707.81 ± 83.14^{c}
	15	0.66 ± 0.05^{b}	41.52 ± 3.24^{b}	2440.06 ± 212.29^{a}
$CaCl_2$ (0.1 M)	10	0.61 ± 0.03^{b}	$11.77 \pm 0.09^{d,e}$	6.12 ± 0.19^{d}
	15	3.07 ± 0.02^{a}	11.14 ± 0.07^{e}	0.44 ± 0.01^{d}
KCl (0.1 M)	10	1.13 ± 0.04^{a}	15.09 ± 0.51^{d}	2338.44 ± 104.07^{a}
	15	1.05 ± 0.04^{b}	19.35 ± 0.44^{c}	2121.21 ± 104.06^{b}

*Values indicate means ± standard deviation.
**Different superscripts in a column for each impregnation solution show statistical differences among means ($p < 0.05$).

asparagine content of potatoes. Amrein et al. [39] suggested that free asparagine level was a limiting factor in acrylamide formation. Changes in the fructose and glucose concentrations of impregnation solutions were found statistically insignificant between two process time of potato strips exposed to VI in distilled water ($p > 0.05$). In Table 1, glucose content of solution for 10 min VI application was 9.60 μg/mL while it increased to 33.70 μg/mL. Pedreschi et al. [36] reported that the content of reducing sugars such as glucose, fructose, and sucrose in potato slices decreased slightly with an increase in soaking time due to water extraction, but the asparagine content tended to remain constant even during 90 min of soaking. Our results were in good agreement with Pedreschi et al. [36].

When sodium chloride solution was used as an impregnation solution (Table 1), the asparagine concentration in the immersion solution was 1.04 μg/mL for the VI pre-treatment applied for 10 min, and it decreased to 0.66 μg/mL for the VI pre-treatment applied for 15 min ($p < 0.05$). A similar trend was also found for the fructose content of impregnation solution, which decreased significantly as pre-treatment duration increased ($p < 0.05$). On the other hand, the glucose content of impregnation solution increased by about 43% with a 5-min increase in processing time ($p < 0.05$). The concentration of free L-asparagine in potato and wheat flour was higher than in reducing sugars [39,40], so removal of L-asparagine, one of the precursors of acrylamide, might have an important role in inhibiting the acrylamide synthesis [41]. Abou-Zaid [38] found a similar decrease in the asparagine content in the study in which potato slices were immersed in 1% NaCl solution as a pre-treatment but reported that the effect of this decrease remained at a low level.

When calcium chloride solution was used as an impregnation solution (Table 1), the difference in the asparagine contents of impregnation solutions between two pre-treatment durations was statistically significant ($p < 0.05$). The highest concentration of asparagine in impregnation solution (3.07 μg/mL) was found in VI pre-treatment for 15 min among the treatments. Interestingly, the changes in glucose and fructose contents of solutions between two pre-treatment durations were found statistically insignificant ($p > 0.05$) although glucose content reduced from 6.12 to 0.44 μg/mL. This could be due to the fact that all values in the table were compared statistically.

In the use of potassium chloride as a VI solution (Table 1), the pre-treatment time had a significant effect on the asparagine, fructose, and glucose contents of impregnation solution ($p < 0.05$). When the VI process time increased from 10 to 15 min, the glucose content of impregnation solution reduced from 2338.44 to 2,121.21 μg/mL. Unlike asparagine and glucose, fructose contents of impregnation solutions increased with a 5-min increase in pre-treatment time ($p < 0.05$).

3.2 Acrylamide contents

After the VI pre-treatments of potato strips in different solutions (distilled water, NaCl, $CaCl_2$, and KCl) for two different times (10 and 15 min), deep frying was carried out in vegetable oil at 175°C for 5 min, and acrylamide analysis in French fries was determined by GC-MS. Amrein et al. [42] reported that the frying medium (oil) plays an important role in the formation of acrylamide in starchy food products. In this study, the acrylamide contents of fries decreased from 0.82 to 0.24 μg/g when pre-treatment time was increased from 10 to 15 min in potato strips pre-treated by VI in distilled water (Table 2). This reduction was found

Table 2: Changes in acrylamide contents of French fries produced from raw potato strips pre-treated by VI in four different solutions for different times

VI exposure time (min)	Acrylamide concentration of French fries* (µg/g)			
	Impregnation solution			
	Distilled water	NaCl	$CaCl_2$	KCl
10	0.82 ± 0.05[a**]	0.72 ± 0.01[a]	0.24 ± 0.02[a]	0.35 ± 0.03[a]
15	0.24 ± 0.01[b]	0.07 ± 0.01[b]	0.25 ± 0.03[a]	0.04 ± 0.01[b]

*Values indicate means ± standard deviation.
**Different superscripts in a column show statistical differences among means ($p < 0.05$).

statistically significant ($p < 0.05$). Gökmen and Şenyuva [43] reported that the acrylamide content was 0.66 µg/g in potatoes immersed in water for 15 min and decreased to 0.59 µg/g after soaking for 60 min. In our study, VI pre-treatment in distilled water for 15 min reduced the acrylamide content of fries more dramatically in comparison to their study. In another study [2], it was reported that simple immersion of potato slices in warm water for 120 min reduced acrylamide formation by 30%, and heat-treatment of potato slices at 50°C for 80 min resulted in a 90% reduction in the acrylamide content of fries. In a study on the use of ultrasonication as a pre-treatment to reduce acrylamide formation in fried potatoes, Antunes-Rohling et al. [44] found that soaking potatoes in water for 30 min could decrease the total acrylamide content of fries by about 70%. They reported that this decrease increased to 83% when soaking at 42°C was supported by ultrasonication pre-treatment. Williams [45] stated that soaking potatoe slices for a short time before frying was not effective in acrylamide formation; however, in a study by Abou-Zaid [38], immersing potato slices in tap water for 60min reduced the acrylamide content of fries by 35.6%. Similar to Abou-Zaid [38], Pedreschi et al. [33] reported that acrylamide content decreased by 38% in potato slices kept in distilled water for 90 min and then fried at 170°C. It has been suggested that metal cations (Na^+, Ca^{2+}, and K^+) prevent the Schiff base and thus acrylamide in the Maillard reaction and that the food matrix forms a complex with asparagine or asparagine–glucose adduct [23]. In our study, the acrylamide content of French fries was 0.72 µg/g for the pre-treatment containing sodium chloride solution for 10 min, and it reduced sharply to 0.07 µg/g when the pre-treatment time was 15 min (Table 2). This decrease in acrylamide contents of fried potatoes was also found statistically significant ($p < 0.05$). Similarly, Kolek et al. [46] reported that the addition of NaCl to an aqueous model reaction significantly reduced the formation of acrylamide. In a study by Gökmen and Şenyuva [43], the acrylamide content was 0.43 µg/g for potatoes immersed in 0.1 M NaCl solution for 15 min and decreased to 0.30 µg/g in potatoes immersed for 60 min. In a study on potato chips, Pedreschi et al. [36] reported that immersion of potatoes in NaCl solution for 5 min prior to frying reduced the acrylamide content of potato chips fried at 120, 140, and 160°C by 97, 92, and 82%, respectively. On the other hand, Abou-Zaid [38] reported that immersion in 1, 2, and 3% NaCl solutions decreased the acrylamide contents of potato slices by 38.9, 42.2, and 51.1%, respectively. Gökmen and Şenyuva [43] and Açar et al. [47] successfully used calcium chloride solution to reduce the acrylamide formation in potato slices and snack foods and reported that increasing the Ca content of these products could decrease the acrylamide content in French fries because the Schiff base, responsible for acrylamide formation, could be inhibited. Calcium cation can prevent the formation of Schiff base, which is one of the key compounds that may lead to acrylamide [43]. Kalita and Jayanty [23] immersed potato slices in 0.1 M $CaCl_2$ and vanadyl sulfate ($VOSO_4$) solutions for 60 min before frying and reported that reduction ratios in acrylamide formation by $CaCl_2$ and $VOSO_4$ were 79.8 and 92.5%, respectively. Similarly, Gökmen and Şenyuva [43] reported that soaking potato slices in 0.1 M $CaCl_2$ solution inhibited acrylamide formation by 95% during frying. In our study, difference in acrylamide concentration between samples pre-treated in $CaCl_2$ solution for 10 and 15 min by VI was found statistically insignificant ($p > 0.05$) (Table 2). On the other hand, in French fries prepared with potato strips pre-treated in KCl solution, the acrylamide level of 0.35 µg/g for the treatment time of 10 min decreased significantly to 0.04 µg/g for the treatment time of 15 min ($p < 0.05$).

The acrylamide content (0.82 µg/g) of French fries prepared with potato strips pre-treated in distilled water by VI for 10 min was used as a relative value, and the acrylamide contents that were relative to this value were calculated to obtain relative reduction rates for acrylamides in fries. Changes in the relative acrylamide reduction rates of French fries are given in Figure 2. VI pre-treatment for

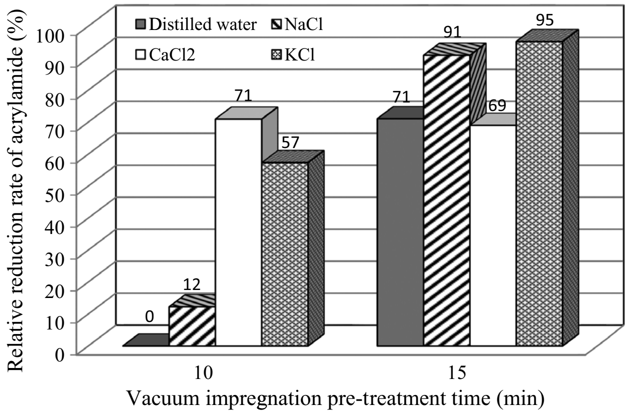

Figure 2: The effect of VI pre-treatment solution and duration for raw potato strips on the relative reduction rates of acrylamide contents in French fries (ratios are relative to the acrylamide contents of French fries produced from raw potato strips pre-treated by VI in distilled water for 10 min).

15 min was more effective than that for 10 min in general. In comparison to VI in distilled water for 10 min, VI in KCl solution for 15 min applied to potato strips reduced the acrylamide content of French fries by 95%, which was followed by a pre-treatment in NaCl solution for 15 min (91%).

Pearson correlation coefficients (n = 24) among the acrylamide concentration of French fries and the asparagine, fructose, and glucose contents of impregnation solutions are given in Table 3. While acrylamide contents in fries were positively and significantly correlated with the fructose concentration of solutions ($r = 0.43$, $p < 0.05$), a negative correlation coefficient ($r = -0.44$) was found between glucose and asparagine contents of impregnation solutions ($p < 0.05$).

Table 3: Pearson's correlation coefficients (r) among the acrylamide content of French fries and the asparagine, fructose and glucose contents of impregnation solutions after the VI pre-treatment of raw potato strips (n = 24)

Parameter	Acrylamide	Asparagine	Fructose	Glucose
Acrylamide	1.00	0.02	0.43*	−0.27
	—	(0.92)	(0.04)**	(0.20)
Asparagine	—	1.00	−0.22	−0.44*
	—	—	(0.31)	(0.03)
Fructose	—	—	1.00	0.37
	—	—	—	(0.07)
Glucose	—	—	—	1.00
	—	—	—	—

*Values indicate that correlation coefficients are statistically significant ($p < 0.05$).
**Values in parenthesis are the level of significance for the Pearson's correlation coefficients.

4 Conclusion

In this study, raw potato strips were pre-treated by VI in four different solutions (distilled water, NaCl, KCl, and $CaCl_2$, 0.1 M) for 10 and 15 min, and strips were deep fried in sunflower oil at 175°C for 5 min. The effect of these pre-treatments on the acrylamide contents of fries was determined. VI pre-treatment in 0.1 M KCl and NaCl solutions for 15 min reduced the acrylamide contents of fries by 95 and 91%, respectively, and immersion in distilled water reduced the formation of acrylamide by 71% in comparison to the pre-treatment in distilled water for 10 min. VI pre-treatment time of 15 min was more effective in reducing acrylamide contents of French fries than that of 10 min. In the literature, dipping or immersing potatoes in similar solutions under atmospheric pressure for a longer time have been reported, but this study showed that VI could successfully accelerate the mass transfer of cations in solutions and can have a great potential in industrial applications due to its speed. Reduction in the levels of asparagine, glucose, and fructose contents of raw potatoes could be achieved by this process in a very short time. On the other hand, the infusion of cations from NaCl, $CaCl_2$, and KCl into potato strips was likely to occur during the VI process when it was applied under a vacuum pressure of less than 70 kPa for a prolonged time, which might result in an interaction with the sensorial characteristics of French fries. In conclusion, this study showed that VI process could be potentially used as a pre-treatment for raw potatoes, and to decrease the acrylamide contents of fried potato products. Meanwhile, the effect of this process on sensory properties of fries should be studied in future studies.

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Conflict of interest: Authors state no conflict of interest.

Ethical approval: The conducted research is not related to either human or animal use.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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