Acrylamide Reduction in Potato Chips by Selection of Potato Variety Grown in Iran and Processing Conditions

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Abstract:

Background

Acrylamide as a possible carcinogen is known to form in heated carbohydrate-rich food such as potato chips. In this study, the effect of three potato varieties (Agria, Sante and Savalan) and two blanching conditions ((75˚C for 9 min and 83˚C for 2.5 min) on the concentration of precursors and acrylamide reduction in potato chips was investigated.

Results

Results revealed that potato variety and blanching time-temperature ere important parameters for acrylamide formation in potato chips. Acrylamide content in Sante variety potatoes, which contained the highest amount of reducing sugars, was found to be the highest (8825µg/kg). However, Savalan, containing the highest asparagine concentration showed the lowest amount of acrylamide due to its lower reducing sugar content. Blanching reduced acrylamide formation. It was more efficient at 75˚C for 9 min, with an average reduction of 74%. The effect of three frying temperatures (170, 180 and 190˚C) on acrylamide formation was also studied just for the Agria potato variety. Increasing frying temperature led to a significant increase in acrylamide formation.

Conclusion

Potato variety and processing conditions were important parameters for acrylamide formation in potato chips. The combination of a suitable variety and appropriate processing conditions could considerably reduce acrylamide content.

Keywords: acrylamide, potato chips, blanching, variety

1. **Introduction**

Formation of acrylamide probable human carcinogen (IARC, 1994) and a neurotoxicant (LoPachin, 2004), in heated carbohydrate-rich foodstuffs attained recent public concern so reduction of acrylamide content has been the subject of great interest to many researchers (Açar et al., 2010; Anese et al., 2009; Gökmen and Şenyuva, 2007; Mestdagh et al., 2008a; Pedreschi et al., 2009). It is now widely accepted that acrylamide is formed during Millard reaction between the amino acid asparagine and reducing sugars at temperatures above 120˚C (Amrein et al., 2003; Becalski et al., 2003; Mottram et al., 2002; Stadler et al., 2002; Tareke et al., 2002; Yaylayan et al., 2003).

The highest amount of acrylamide is formed in fried potato products like chips and French fries due to the presence of large concentration of acrylamide precursors in potato and also the use of high temperatures during their frying (Ahn et al., 2002; Williams, 2005).

Many previous studies demonstrated that increasing the frying temperature led to more acrylamide formation in fried potato products, especially at temperature higher than 175˚C (Gertz and Klostermann, 2002). According to these results, there may be a way for acrylamide reduction in potato chips by lowering frying temperature.

On the other hand acrylamide concentration detected in heated foods is the result of concurrent formation and degradation. At higher temperatures and prolonged processing time, the formation of acrylamide seems to decrease in food systems. This reduction was attributed to the predominant rate of acrylamide degradation by the rate of its formation during frying (Mottram et al., 2002; Rydberg et al., 2003; Tareke et al., 2002; Taubert et al., 2004).

In potato since free asparagine content is sufficiently high and varies far less than reducing sugar concentration, the latter is considered as determining factor for acrylamide formation in potato products. Concentration of acrylamide precursors in raw potato mainly depends on potato variety, agricultural and storage conditions (Amrein et al., 2003; Williams, 2005).

Thus an alternative key point which could be taken into consideration to reduce the content of acrylamide in potato chips is reduction of acrylamide precursors either by using potatoes varieties with a naturally low precursor content or pre-treating the potatoes such as blanching before frying (Haase et al., 2003; Kita et al., 2004; Matthäus et al., 2004; Pedreschi et al., 2004).

In industrial production of potato chips, blanching is used as a common pre-treatment (or as a unit operation) to extract reducing sugar in order to reduce browning, to inactivate enzymes such as polyphenol oxidase and to reduce the oil uptake by gelatinization of the surface starch. Lower blanching temperatures would, however, require much longer blanching time (Mestdagh et al., 2008b; Pedreschi et al., 2006). There are many reports that claim a reduction of the acrylamide formation in potato products by changing the blanching treatment (Mestdagh et al., 2008b; Pedreschi et al., 2004 and 2006). However comparison of reported results with industrial production is not easy because some of them reported low blanching temperatures or long blanching times which may not be relevant to industrial chips production. In addition, reported processing conditions such as frying temperatures differ to some extent with commercial practice.

The objective of this study was to investigate the effect of potato variety and different blanching conditions from an industrial view of point to reduce acrylamide formation in potato chips.

Therefore three different potato varieties (Agria, Sante and Savalan) and two different blanching conditions (75˚C for 9 min and 83˚C for 2.5 min) were selected in consultation with local industries. Also, in order to determine whether frying at a somewhat higher temperature for shorter time can reduce acrylamide formation due to acrylamide degradation, three different frying conditions which are common in potato industry were studied only for Agria variety, the most common variety used in Iran.

2. **Material and methods**

2.1. Potato and oil characteristics

Samples of the potato varieties Agria, Sante and Savalan cultivated at the experimental farm under the same conditions at the Seed and Plant Improvement *Institute of The Ministry of Jihad-E-Agriculture, were used.*

Three varieties were studied: (i) Agria, a common chip potato variety in Iran (ii) Sante, the second most common potato using in potato chips industry in Iran and (iii) Savalan, a new hybrid variety introduced by agriculture administration of Iran as a suitable variety for chip production because of its higher solids content. Potato samples were stored in 10 ˚C and 90% humidity until used for chip production. The oil used for frying was commercial frying oil (Behshahr industry) purchased from local markets.

2.2. Production of potato chips:

Potatoes were washed, peeled and sliced by hand slicer into sheets of 1.5 mm thickness. Potato slices were rinsed and soaked in distilled water for 1 min to eliminate surface starch.

Blanching was done by immersing 100 potato slices in 10 liters of water (ratio of potato to water (g/g) of ~ 0.03); it was performed in two time-temperature conditions: (a) 83 ˚C for 2.5 min (HTST), (b) 75 ˚C for 9 min (LTLT).

Frying conditions: 20 potato slices from Agria variety were fried in a fryer containing 5 liters of oil using the following three time-temperature combinations: (a) 170 ˚C for 5 min, (b) 180 ˚C for 4.15 min and (c) 190 ˚C for 3.5 min. The two other varieties were fried at 180 ˚C for 4.15 min. as standard frying process.

These conditions allowed the fried chips to reach final moisture contents of ~1.5 g water/100 g (wet basis). After frying they were cooled to room temperature and stored in -20 ˚C for further analysis.

It should be noted that blanching and frying temperature combinations were selected after consultation with Iranian potato chip producers and were based on preliminary experiments. To obtain potato chip samples with a minimum amount of acrylamide under studied conditions, it was decided to use samples that would be produced from the best selected variety (with the lower acrylamide content after frying) and then processed under optimal blanching and frying conditions.

2.3. Analysis

2.3.1. Dry matter content. The dry matter of fresh potato tubers of each three varieties was determined after being dried at 65˚C and until constant weight was achieved (AOAC, 2005).

2.3.2. Reducing sugars. Glucose and fructose amount were determined by High Performance Liquid Chromatography (HPLC) using an instrument equipped with a refractive index(RI) detector according to Matsuura-Endo et al., 2004 with some modifications.

Briefly, 10 grams frozen tuber pieces were homogenized in 150 ml 80% (v/v) ethanol for 5 min, and sugars in the homogenate were extracted at 80°C for one hour. After centrifugation at 1500 *g* at 4°C for 20 min, the resultant supernatant (ethanol extract) was dried under vacuum and dissolved in distilled water, then zinc sulfate 5% (5ml) and barium hydroxide 0.3N (4.7ml) solutions were added to precipitated impurities. After centrifugation (10000 g for 10 min), 40 ml supernatant was collected in a tube, dried at room temperature, then dissolved in 2ml distilled water, and passed through a 0.2-μm Omnipore membrane filter (Millipore, Tokyo, Japan).The filtrate contents of glucose and fructose were determined by high performance liquid chromatography with a Urocath-H column (30 cm × 10 mm) and with deionized water (pH=2) as mobile phase, the flow rate was 0.7 ml/min. Quantification of sugars in samples was performed by standardization with external glucose and fructose. All measurement of sugars was carried out in three replicates.

2.3.3. Free amino acids. Potato free amino acids were extracted and derivatized according to Butikofer and Ardo (1999). O-phtaldialdehyde (OPA) and fluorenylmethyl chloroformate (FMOC) amino acids were measured by HPLC Hewlett-Packard model 1100 equipped by model 1046A fluorescence detector).A Hypersil ODS 250× 4mm column with 20×4mm pre-column were used. All measurements of amino acids were carried out in three replicates.

2.3.4. Acrylamide. Acrylamide was analyzed as the dibromo derivative by gas chromatography-mass spectrometry (GC-MS) using the method of Castle et al. (1993) with some modifications. Briefly, 10 g of potato chips sample were homogenized in 100 ml distilled water with internal standard methacrylamide (500μg/kg) and then 5 ml Carrez 1 and 5 ml Carrez 2 solutions were added and homogenized using an Ultra-turrax hemogenizer for 2 min.

After centrifugation at 6500 Xg for 10 min at 5°C to solidify oil, an aliquot (25 ml) of the supernatant was derivatized through bromination with a brominating solution(potassium bromide, hydrobromic acid and saturated bromine water) The sample was kept at 4˚C overnight, and the excess bromine was neutralized by addition of sodium thiosulfate (0.7 M). Sodium sulfate (15 g) was added and dissolved in the mixture. The analyte was then extracted with ethyl acetate [2×20 ml]. The organic fraction was passed through sodium sulphate (1g) and evaporated with a rotary evaporator at 40˚C to approximately 1 ml, followed by nitrogen stream evaporation to 200 μl The brominated extract (1 μL) was analyzed on a Varian model 3800 gas chromatograph coupled to Varian model 1200 mass spectrometer operated in the selected ion monitoring mode. The GC column was a 30 m ×0.25 mm fused silica capillary with a 0.25 μm HP-5MS phase. Monitoring ions *m/z* 106, 108, 150 and 152 were used to characterize brominated acrylamide and *m/z* 120 and 122 were used to characterize brominated methacrylamide. The ion *m/z* 150 and 120 were used to quantify brominated acrylamide and brominated methacrylamide respectively.

2.4. Statistical Methods and data analysis

All determinations were conducted independently in triplicate. The experiments were factorial with a completely randomized design. Statistical analysis of the data was performed through an analysis of variance (ANOVA) using SPSS statistical software version 16. Duncan's multiple range test was used to determine any significant difference among the treatments at a 95% confidence level.

Results and discussion

2.2. Dry matter content of potato varieties

Dry matter contents of Agria, Santé and Savalan were 20.04, 19.78 and 24.44% respectively. Savalan showed significantly higher dry matter content. The higher dry matter content resulted in higher yield in potato chip processing. Therefore it can be considered a valuable property of Savalan compared to the other two varieties. However it reported that chip texture can be affected by the dry matter content of raw potato tubers; chips prepared using potatoes with a high dry matter content (above 25%) showed a hard texture (Kita, 2002). None of the potato varieties used in this study showed dry matter content more than 25%.

2.3. Reducing sugar and amino acid content

Reducing sugar concentration (Glucose and fructose) in Sante (3512 mg/kg) was significantly higher compared to Agria (2111 mg/kg) and Savalan (1621 mg/kg)). The highest amounts of glucose were seen in Sante (1781mg/kg), Agria (1234mg/kg) and Savalan (985mg/kg) respectively. Fructose amounts were generally lower than those of glucose in all three varieties, but it tended to change to glucose.

The concentrations of free asparagine of the different varieties are listed in Table 1 together with those of other free amino acids. The free amino acid profile showed that although the amino acids contents are variable in different varieties, asparagine is the predominant amino acid in all three of them. These results are in agreement with those of (Eppendorfer and Bille, 1996; Martin and Ames, 2001). Savalan variety was found to have the highest amount of asparagine (1916mg/kg) compared to the other varieties ($p<0.05$). There was no significant difference between Agria and Santé based on aspargine concentration.

Acrylamide content of standard frying process.

Significant differences were observed in acrylamide content between the potato varieties when fried at 180°C ($p<0.05$). Acrylamide content in chips prepared from Sante, Agria and Savalan was 8825μg/kg, 6350μg/kg and 5112μg/kg, respectively (Fig.2). Sante which had the highest concentration of reducing sugars (3512 mg/kg) compared to the other varieties showed the highest acrylamide content although its aspargine content was less than Savalan. The lowest acrylamide amount was formed in Savalan variety which contained the lowest amount of reducing sugar but the highest aspargine content in comparison with the other two varieties in this experiment. This may suggest that the presence of the highest amount of asparagine in potato does not necessarily cause formation of the highest amount of acrylamide in fried potato samples. These results were confirmed by evaluating the relationship between acrylamide content and its precursors. The correlation of acrylamide formation with the reducing sugars (i.e., glucose and fructose contents of all three varieties before and after blanching) was strong (R^2=0.98), but asparagine concentration alone showed a weaker correlation with acrylamide content (R^2 =0.33). These results are in agreement with those reported by other authors suggesting that reducing sugar amount is an important factor for determining acrylamide formation in potato chips (Amrein et al., 2003; Wicklund et al., 2006; Williams, 2005).

3.3. Effect of frying temperature on Agria variety

Acrylamide amount of chips produced from Agria variety potatoes at different frying temperature (170-180-190˚C) were significantly different ($p<0.05$). As frying temperature increased, acrylamide amount tend to increase too. Acrylamide formation showed a significant increase by 60% in control (unblanched) samples, as frying temperature increased from 170 to 190°C in control samples.

It was shown that when the oil temperature was higher than 175°C the energy input is high enough to increase both temperature and moisture evaporation for the same duration which accelerated the acrylamide formation (Gertz and Klostermann, 2002; Gökmen and Şenyuva, 2006a).

A preliminary experiment was performed to determine appropriate time-temperature conditions to reduce the moisture content of potato slices from approximately 75% to 1.5%. Results showed that the required time for reaching a moisture content of 1.5% in potato chip samples was 3.4, 4.15 and 5 min for temperatures 170, 180 and 190˚C, respectively. Frying conditions of 190˚C for 3.5 min were selected to determine whether high temperature for a short time can reduce acrylamide formation due to acrylamide degradation during frying. Applying a high temperature (190˚C) even for a short frying time (3.5min) increased acrylamide amount compared to lower temperature and longer time frying conditions. Gokmen et al., 2006b stated that acrylamide content of potato chips decreased after 5 and 8 min frying at 190˚C and 170˚C respectively, which are longer times than those we used in this study (190˚C for 3.5 min and 170˚C for 5 min). These results are according to Taubert et al. (2004) who showed that degradation of acrylamide occurred at a higher temperature than commonly used t in domestic or industrial production.

3.4. **Blanching effect on reducing sugars and asparagine**

In industrial potato processing, blanching is carried out usually within the range of 80–100˚C for short times between 20s to 15 min. It is known that blanching at high temperature may result in higher oil absorption during frying, loss of firmness and undesirable texture compared to unblanched slices (Alvarez et al., 2000; Andersson et al., 1994; Canet et al., 2005).

Blanching in the range of 55 to 75˚C for a long time tends to improve the textural quality such as firmness of cooked potato and lowered the oil uptake during frying (Mestdagh et al., 2008b; Verlinden et al., 2000). On the other hand lower blanching temperatures would tend to activate the pectin methyl esterase (PME) enzyme which in turn makes the cell wall structure more rigid, enhancing firmness (Agblor and Scanlon, 2000; Aguilar et al., 1997; Canet et al., 2005).

Mestdagh et al., 2008b concluded that application of a blanching pretreatment at temperatures of about 70˚C for about 10 to 15 min should be considered in the industrial production process, depending on the reducing sugar content of raw potato. For the above reasons, to determine blanching effects on acrylamide formation two blanching time-temperature conditions were selected: 75˚C for 9 min (LTLT) which is to some extent similar to the conditions suggested by Mestdagh et al., 2008b and 83˚C for 2.5 min (HTST) which is one of the most common industrially blanching time-temperature in Iran.

Although in preliminary tests two additional blanching conditions were also investigated- 75 ˚C for 2.5 min and 83 ˚C for 9 min- in the following study they were ignored owning to the adverse effects on potato chip quality. The aim of our study was to produce potato chips not only with low acrylamide content but also with desirable texture and colour for acceptance of the product by the consumer. Blanching for a short time (2.5 min) at 75˚C was not sufficient to leach the reducing sugars, thus leading to darker coloured chips. Regarding blanching at 83˚C for 9 min, this caused undesired light-coloured chips after frying, as well as their texture being insufficiently firm according to panelists' evaluation (a group of six trained panelists). In addition , the chips contained a higher oil content than the standard level in Iran (observed 54% instead of the maximum 43%). These changes resulted from high temperature for a long time, leading to a lack of crispness and inferior texture properties.

Our results revealed that blanching was effective both in reduction of both reducing sugar and asparagine content. LTLT blanching treatment led to a decrease of reducing sugars and asparagine amount to a higher extent than the HTST blanching condition. The former treatment decreased reducing sugars and asparagine content up to 77% and 64% and the latter by 66% and 40% respectively compared to control samples (average values of the three varieties) (Fig.1). Extraction of reducing sugars and asparagine contents was positively correlated with acrylamide formation after frying in each treatment (Fig.2). Blanching treatments at 75˚C for 9 min and 83˚C for 2.5 min could decrease acrylamide formation in samples with 74% and 62.9% respectively (average values of the three varieties). Regarding the frying conditions, acrylamide reduction in Agria variety was seen in all blanched samples especially in LTLT ones even at 190˚C (2410 µg/kg (LTLT) and 3700 µg/kg (HTST)) (Fig.3).

These results are in agreement with other studies in which the reduction effects of blanching were in the same range for precursors and acrylamide (Haase et al., 2003; Kita et al., 2004; Pedreschi et al., 2004)). However, Viklund et al. (2010) stated that the decrease in acrylamide content induced in potato chips by blanching was higher than the reduction of acrylamide precursors probably due to entrapment of water in the gelatinized starch network of potato which limits molecule diffusion and thus availability of water-soluble acrylamide precursors for acrylamide formation in the surface. Pedreschi et al. (2004 and 2006) also reported that long time blanching treatment (50˚C for 70 min and 70˚C for 40 min) reduced potato reducing sugars and consequently acrylamide amount by 97% and 91% on average, at the three frying temperature (150,170 and 190˚C).

Both blanching treatments used in this study were able to decrease reducing sugars concentration of potato samples under 1000 mg/kg with the exception of Sante variety.

This concentration was declared as critical point in acrylamide formation in roasted and baked potato products by Biedermann-Brem et al., 2003. The minimum acrylamide amount is formed under this critical point, which is in accordance with the reducing sugar content necessary for favorite colors in chips, otherwise chip colour may be dimmer. On the other hand, potato with a reducing sugar concentration of less than 200 mg/kg is not suitable for chip production, because the presence of reducing sugar is important to produce the gold color and roasting flavor typical of potato products. In this study none of the blanching conditions resulted in reducing sugar content lower than the critical value (200 mg/kg) even in Savalan.

The presence of such a good correlation between acrylamide reduction and chip quality suggests that blanching could be used as an effective and practical way to produce high quality potato chips with low acrylamide amount.

Considering the lower acrylamide content in Agria samples blanched under LTLT conditions and fried at 170˚C for 5 min (435µg/kg), it was interesting to evaluate the acrylamide formation in Savalan variety blanched and fried under the same conditions. As expected, these samples showed the lowest acrylamide formation (170µg/kg) due to the naturally lower content of reducing sugars of Savalan variety and application of better blanching and frying conditions.

4. **Conclusion**

Regarding increasing serious concern about acrylamide regularly consumed through dietary components, especially in potato chips, there have been extensive research efforts to minimize acrylamide formation during food processing

In the present work, three potato varieties - Agria, Sante, and Savalan- were studied. The potato variety with lower reducing sugars (Savalan) led to minimum acrylamide content in the final product in both control and blanched samples.

These results showed that raw material selection was an important factor in minimizing acrylamide formation in potato chips and Savalan was the most suitable variety for chip production. Blanching before frying caused considerable reduction in acrylamide amount in all three varieties. The LTLT blanching treatment resulted in lower acrylamide formation after frying. The highest potential of acrylamide formation was seen at 190˚C; even decreasing frying time at 190˚C compared to 180˚C (the most common industrial frying temperature) could not decrease acrylamide amount. Therefore, it is recommended to use lower frying temperatures in common industrial potato processing, which will lead to a reduction of acrylamide formation.

Finally both raw material selection and processing conditions like blanching and frying temperature are effective in reduction of acrylamide formation. The combination of these practical factors can considerably reduce acrylamide amount during potato chips processing.

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Table 1

Concentration of free amino acids of different potato variety (Agria, Sante and Savalan)

Free amino acids	**Agria (mg/kg)**		**Savalan (mg/kg)**		**Sante (mg/kg)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Asparagine	1117	65	1870	73	1268	69
Serine	199	20	107	12	200	15
Glysine	100	13	98	13	109	11
threonine	160	15	112	12	195	16
Arginine	330	19	440	19	342	20
lysine	288	13	311	17	233	14
Alanine	151	11	121	10	161	15
Tyrosine	100	9	119	11	125	10
Valine	335	14	361	15	295	16
Methionine	131	11	131	17	108	14
Tryptophan	115	10	85	8	82	9

Isoeucine	165	9	172	13	173	12
Leucine	139	6	112	9	140	9
Phenylalanine	206	10	213	12	188	10
Aspartic acid	499	16	509	17	547	16
Glutamine	712	20	861	22	765	24
Glutamic acid	331	12	374	13	213	10
cystine	1012	55	1138	48	912	42

[a] On a fresh weight basis. Values are means of three replicates

(A)

(B)

Fig. 1. Reducing content (A) and Asparagine content (B) of potato varieties blanched at different temperature–time combinations

Fig. 2. Acrylamide content of potato varieties blanched at different temperature–time combinations

Fig. 3. Acrylamide content of potato slices blanched at different temperature–time combinations and fried at different temperatures