

The Content of Acrylamide in Deep-fat Fried, Shallow Fried and Roasted Potatoes

Irisa Murniece, Daina Karklina, and Ruta Galoburda

Abstract—Potato is one of the main components of warm meals in Latvia. Consumption of fried potatoes in Latvia is the highest comparing to Nordic and other Baltic countries. Therefore acrylamide (AA) intake coming from fried potatoes in population might be high as well. The aim of the research was to determine AA content in traditionally cooked potatoes bred and cultivated in Latvia. Five common Latvian potato varieties were selected: Lenora, Brasla, Imanta, Zile and Madara. A two-year research was conducted during two periods: just after harvesting and after six months of storage. The following cooking methods were used: shallow frying (150 ± 5 °C); deep-fat frying (180 ± 5 °C) and roasting (210 ± 5 °C). Time and temperature was recorded during frying. AA was extracted from potatoes by solid phase extraction and AA content was determined by LC-MS/MS. AA content significantly differs ($p < 0.05$) in potatoes per variety, per each frying method and per time.

Keywords—potato, frying, roasting, variety, acrylamide, Latvia.

I. INTRODUCTION

POTATO (*Solanum tuberosum* L.) is one of the world's major staple food crops. Potatoes are grown in approximately 80% of all countries and worldwide production stands in excess of 320 million tons in 2007 [1]. Evaluating the consumption of potatoes in the world in 2005, Latvia took the eighth place with a consumption of 114 kg per capita which increases yearly and from the results of the Norwegian research, it can be concluded that potatoes play a significant role in the balance of nutrients of the Latvian inhabitants, constituting about 70% of the total vegetable consumption [2], [3]. Therefore, preparing potatoes by different cooking methods, it is important to pay attention not only to nutritional value of potatoes but also to harmful components for instance acrylamide (AA, 2-propenamide, CAS RN 79-06-1). It has recently been reported that AA is a compound classified as a probable carcinogen and is present in various foods processed at high temperature [4], [5].

AA is formed during heating of food materials such as frying, deep-fat frying or baking [6].

The content of AA in fried potato foods depends on potato genotype, growing (growing location, fertilization, temperature and maturity) and storage conditions (temperature, relative humidity of the air and duration) as well

as chemical composition [7].

The color of the food surface is the first quality parameter evaluated by consumers and is critical in the acceptance of the product, even before it enters the mouth [8].

Color of foods has been usually measured in units $L^* a^* b^*$ which is an international standard for color measurements, adopted by the Commission Internationale d'Eclairage (CIE) in 1976. Since color can easily be measured, it may be used as an indicator of some Maillard reaction products like AA.

The aim of the research was to determine AA content in traditionally cooked potatoes bred and cultivated in Latvia.

II. MATERIALS AND METHODS

A. Raw material

In cooperation with the State Priekuli Plant Breeding Institute (Latvia), five table potato varieties which can be used for the production of fried potato products were studied: Lenora, Brasla, Imanta, Zile and Madara. Madara is an early maturity variety; Lenora is mid-early, while Zile, Brasla and Imanta are representatives of mid-late varieties. The Madara and Zile varieties are the oldest ones used in the research, developed in 1984, Brasla was developed in 1990, Lenora in 1995, while the youngest variety Imanta was developed in 2006 [9]. Detailed description of each potato variety is presented in Table I.

Tuber samples of varieties were analyzed after harvesting and after six months of storage. Potatoes were stored at an air temperature of 5 ± 1 °C and at a relative air humidity of $80 \pm 5\%$.

The tubers of selected varieties were produced in the fields of the State Priekuli Plant Breeding Institute. The potatoes were grown in sandy loam soil with a pH_{KCl} of 6.1 and an allowable amount of phosphorus and potassium. In the first year the ratio of N:P:K was 13:10:15, but in the second year it was 11:19:20. The soil cultivation was performed using the agrotechnology according to the existing crop management.

Comparing the years of potato growing, the atmospheric temperature during the growing season was very similar, but the rainfall level differed in both growing years [9].

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TABLE I
DESCRIPTION OF THE STUDIED POTATOES

| Potato variety | Shape of tubers | Color of skin and flesh of potato tubers | Suitability for Cooking type | Variety type | Registration year |
|----------------|-----------------|--|------------------------------|--------------|-------------------|
| 'Zile' | oval | skin and flesh yellow | B-BC | medium-late | 1984 |
| 'Brasla' | round | skin and flesh yellow | BC | medium-late | 1990 |
| 'Madara' | round oval | skin yellow and flesh light yellow | B | early | 1984 |
| 'Lenora' | round oval | skin and flesh yellow | B | medium-early | 1995 |
| 'Imanta' | oblong oval | skin yellow with pink eyes flesh white | BC-C | medium-late | 2006 |

B. Frying and Roasting

Potato tubers of approximately similar size (4 – 6 cm) and weight of 200 ± 15 g each were selected, washed, hand-peeled and cut in three ways: for shallow frying potatoes were sliced into 0.7×1.0 cm and 3 – 4 cm long chips, fried at 150 ± 5 °C for 7.0 ± 0.3 min, while for deep fat frying they were sliced into 0.6×0.6 cm and 4 – 5 cm long chips and fried at a temperature of 180 ± 5 °C for 4.0 ± 0.3 min. Potatoes prepared for roasting were cut horizontally into halves and roasted at a temperature of 210 ± 5 °C for 25 ± 1.0 min.

Sunflower seed oil "*Floriol*" produced in Hungary was used for frying. The sample potatoes were prepared according to three types of frying: roasting in an oven (potato and oil ratio – 1:0.009), frying in a pan – in a small amount of oil (1:0.04) and in a deep-fat fryer – in a high amount of oil (1:4.9).

Throughout the oven and deep fat frying procedure, the time and temperature were recorded by USB TC-08 Thermocouple Data Logger PICO-Technologist equipment [9].

C. Acrylamide Analysis

Determination of acrylamide was performed at the laboratory of the Chemistry Division 1, National Food Administration.

Solid phase extraction (SPE) was used in preparing potato samples for AA analyses using the SPE columns: Isolute Multimode (500 mg) and Isolute ENV+ (500 mg) from International Sorbent Technology, (UK). LC-MS/MS equipment was used for determining the content of AA. The HPLC column was Hypercarb ($5\mu\text{m}$, $50\text{ mm} \times 2.1\text{ mm}$) from Termo Electron Corporation, Waltham, MA, USA. AA (assay (GC) $\geq 99.9\%$), and methanol (gradient grade) were supplied by Merck, Darmstadt, Germany. Acetonitrile (HPLC-grade) was obtained from Lab-Scan, (Dublin, Ireland). Detailed description of the sample preparation for the analysis and settings of AA analysis are described by Rosén et al. [10].

During analysis the quality aspects were taken into account with regard to sample handling, analytical methods, equipment and analytical procedure. The obtained results were accepted in those cases when the difference between values did not exceed 5%.

D. Glucose and Dry Matter

Dry matter (DM) content of potato tubers was determined by ISO 6496:1999, glucose content by the method described by Somogyi [11], [12].

E. Color Determination

Color of potato samples was measured by *Color Tec-PCM* device (USA). For evaluation of uncooked potato sample

color, potato slice was cut shortly before measurement in order to avoid formation of melanin pigments in non-enzymatic browning reaction which can affect the colour measurement accuracy. For evaluation of fried potato sample color – product was homogenized, transferred to a Petri dish and covered by transparent PP film of $25\mu\text{m}$ thickness, to avoid direct contact between measuring device aperture and product. Color was measured at least in seven various locations of the sample in order to obtain higher accuracy after calculation of the mean value. For data analysis ColorSof QCW software was used.

The color is defined by three co-ordinates according to CIE lab system (CIE, Commission Internationale de l'Eclairage): L^* (lightness) the vertical co-ordinate that runs from $L^* = 0$ (black) through grey to $L^* = 100$ (white), a^* (redness) the horizontal co-ordinate that runs from $-a^*$ (green) through grey to $+a^*$ (red), and b^* (yellowness) another horizontal co-ordinate that runs from $-b^*$ (blue) through grey to $+b^*$ (yellow) [13], [14].

For evaluation of color change the total color difference ΔE^* was calculated between measurement in fresh and fried samples [15], [16].

F. Statistical Analysis

For statistical analysis, the data were processed using the S-PLUS 6.1 Professional Edition software. Data are presented as a mean \pm standard deviation (SD). The differences between independent groups were specified by two way analysis of variance (ANOVA), and values of $P < 0.05$ were regarded as statistically significant. In case of establishing statistically significant differences, homogeneous groups were determined by Tukey's multiple comparison test at the level of confidence $\alpha = 0.05$.

III. RESULTS AND DISCUSSION

The content of dry matter (DM) is particularly substantial if the potatoes are to be used for frying. According to several authors, the most suitable potatoes are those, whose DM is above 20% [17], [18]. The results of research show that the potato varieties with DM lower than 20% are 'Madara' (18.93%) and 'Lenora' (19.48%) (Table II). The results of the analysis of research data indicate that there is a considerable difference in the DM content in freshly harvested and stored potatoes ($p = 0.005$). The DM content in potato tubers increases during the growing season. Maximum values are reached at different times depending on potato variety and environmental condition. The DM content in potatoes after a six-month storage period increases by 10.71% on average. Increase of the DM is related to the metabolic respiration.

TABLE II
DRY MATTER CONTENT OF THE STUDIED POTATOES

| Type of frying method | Potato variety | 1 st study year | | 2 nd study year | |
|-----------------------|----------------|----------------------------|---------------|----------------------------|---------------|
| | | Before storage | After storage | Before storage | After storage |
| Uncooked (raw) | 'Zile' | 20.16±0.06 | 23.14±0.06 | 24.42±0.12 | 24.82±0.08 |
| | 'Brasla' | 23.36±0.03 | 26.86±0.08 | 25.60±0.09 | 25.85±0.04 |
| | 'Madara' | 18.93±0.07 | 25.83±0.07 | 21.77±0.01 | 22.54±0.01 |
| | 'Lenora' | 19.48±0.10 | 22.54±0.18 | 20.31±0.01 | 25.21±0.06 |
| | 'Imanta' | 24.72±0.05 | 25.58±0.03 | 24.42±0.12 | 24.61±0.01 |
| Roasted | 'Zile' | 31.26±0.09 | 30.67±0.14 | 37.59±0.01 | 34.38±0.04 |
| | 'Brasla' | 36.04±0.08 | 37.56±0.23 | 33.36±0.06 | 34.26±0.06 |
| | 'Madara' | 28.46±0.07 | 39.06±0.14 | 35.83±0.07 | 31.29±0.13 |
| | 'Lenora' | 24.35±0.11 | 34.73±0.17 | 27.55±0.05 | 33.66±0.06 |
| | 'Imanta' | 34.70±0.07 | 43.05±0.20 | 32.71±0.08 | 33.40±0.07 |
| Shallow fried | 'Zile' | 36.55±0.12 | 33.90±0.21 | 40.72±0.09 | 37.80±0.08 |
| | 'Brasla' | 38.88±0.08 | 42.52±0.09 | 41.06±0.03 | 38.59±0.05 |
| | 'Madara' | 35.99±0.09 | 40.03±0.16 | 39.16±0.06 | 35.38±0.08 |
| | 'Lenora' | 30.19±0.08 | 27.76±0.18 | 32.51±0.04 | 31.95±0.11 |
| | 'Imanta' | 48.05±0.11 | 35.44±0.15 | 37.73±0.13 | 37.16±0.13 |
| Deep-fat fried | 'Zile' | 57.49±0.10 | 45.46±0.20 | 59.17±0.08 | 58.07±0.06 |
| | 'Brasla' | 53.89±0.12 | 50.98±0.11 | 63.18±0.05 | 56.41±0.66 |
| | 'Madara' | 50.75±0.06 | 59.32±0.20 | 56.57±0.08 | 50.55±0.06 |
| | 'Lenora' | 59.81±0.10 | 50.75±0.25 | 55.83±0.16 | 48.55±0.06 |
| | 'Imanta' | 61.91±0.13 | 46.44±0.25 | 57.27±0.04 | 61.75±0.15 |

The increase of dry matter in fried potatoes is connected with moisture evaporation from the outer layer of potatoes during the process of frying, thus forming a crispy crust [19]. It is also influenced by the conditions and length of storage. The potatoes which are cut into smaller pieces have a greater surface area and due to that more water evaporates from the product during the frying process.

Moisture content is an important factor influencing the rate of the browning reaction. Browning occurs at low temperatures and intermediate moisture content; the rate increases with increasing water content [20], [21].

The results obtained after mathematical data processing indicate that there exist significant differences in the content of DM in all the applied types of thermal treatment ($p < 0.001$) and varieties ($p = 0.009$). Substantial differences are observed in potato variety 'Lenora' which has the lowest content of DM

in comparison with the potato varieties 'Brasla' and 'Imanta'. Evaluating the differences in the content of DM by the types of heat treatment, the results obtained, indicate a significant difference of mean values of the content of DM among potato genotypes after shallow frying ($p = 0.005$).

The researched glucose content in 100 g of dry weight (DW) before storage (in autumn) is within the range of 0.21–2.60g, but after storage is from 1.44–3.49 g (Table III). In autumn, glucose content in potatoes is lower than in spring after storing, and its content on average increases 2.2 times.

The increase in glucose content in stored potatoes can be explained by starch and sucrose splitting into monomers during storage. The data obtained by statistical analysis also show significant differences in glucose content between the freshly harvested potatoes and those which were stored ($p = 0.002$).

TABLE III
GLUCOSE CONTENT ON DRY MATTER CONTENT OF THE STUDIED POTATOES

| Type of frying method | Potato variety | 1 st study year | | 2 nd study year | |
|-----------------------|----------------|----------------------------|---------------|----------------------------|---------------|
| | | Before storage | After storage | Before storage | After storage |
| Uncooked (raw) | 'Zile' | 1.34±0.02 | 0.21±0.02 | 3.49±0.04 | 2.50±0.08 |
| | 'Brasla' | 2.21±0.05 | 0.33±0.02 | 1.50±0.09 | 1.72±0.20 |
| | 'Madara' | 1.38±0.12 | 0.79±0.10 | 1.44±0.15 | 3.11±0.12 |
| | 'Lenora' | 2.60±0.13 | 2.03±0.09 | 3.14±0.10 | 2.57±0.16 |
| | 'Imanta' | 0.45±0.01 | 0.97±0.17 | 2.17±0.12 | 2.95±0.17 |
| Roasted | 'Zile' | 1.75±0.03 | 0.43±0.02 | 3.16±0.10 | 1.67±0.01 |
| | 'Brasla' | 2.19±0.36 | 0.49±0.01 | 1.00±0.02 | 1.97±0.01 |
| | 'Madara' | 1.42±0.08 | 0.98±0.06 | 1.95±0.12 | 3.31±0.42 |

| | | | | | |
|----------------|----------|-----------|-----------|-----------|-----------|
| Shallow fried | 'Lenora' | 3.10±0.08 | 2.55±0.02 | 2.97±0.20 | 2.65±0.10 |
| | 'Imanta' | 0.77±0.06 | 2.02±0.11 | 1.57±0.02 | 2.69±0.08 |
| | 'Zile' | 1.09±0.04 | 0.26±0.01 | 2.65±0.09 | 1.70±0.06 |
| | 'Brasla' | 1.84±0.11 | 0.28±0.01 | 0.98±0.06 | 1.68±0.01 |
| | 'Madara' | 1.01±0.03 | 1.27±0.04 | 0.66±0.02 | 2.01±0.01 |
| Deep-fat fried | 'Lenora' | 2.09±0.09 | 1.53±0.01 | 3.02±0.22 | 2.69±0.05 |
| | 'Imanta' | 0.26±0.03 | 1.16±0.02 | 1.86±0.03 | 1.81±0.10 |
| | 'Zile' | 0.77±0.02 | 0.29±0.01 | 2.35±0.09 | 0.38±0.02 |
| | 'Brasla' | 1.36±0.03 | 0.17±0.00 | 0.98±0.03 | 0.50±0.01 |
| | 'Madara' | 0.75±0.03 | 0.52±0.01 | 0.89±0.02 | 0.82±0.03 |
| | 'Lenora' | 1.18±0.02 | 1.35±0.02 | 1.64±0.31 | 1.97±0.00 |
| | 'Imanta' | 0.28±0.02 | 0.74±0.06 | 2.14±0.02 | 0.89±0.02 |

The results obtained after the analysis of the research data, as it is in the case of total reducing sugars, indicate a significant difference in the content of glucose among the varieties used in the research ($p = 0.003$), as well as among the types of frying ($p < 0.001$). Evaluating the content of glucose by the types of treatment, significant differences in the content of glucose are observed in shallow fried potatoes comparing freshly harvested fried potatoes with those fried in spring after storage ($p = 0.008$).

The color is one of the factors showing the intensity of the Maillard reaction [22]-[24] and it has been established that color measurements can correlate well with the AA content [25]. The fried potatoes of the variety 'Imanta' have a pronounced difference in total color intensity (ΔE^*), which indicates the likelihood of a higher content of AA in this particular variety. Total color difference in potatoes of variety 'Imanta' is significantly higher comparing other analyzed potato varieties (Fig. 1).

The results obtained after statistical analysis show the significant ΔE^* differences in color of fried potatoes if frying freshly harvested or stored potatoes.

It can be explained by increase of reducing sugars content storing them at low temperature and afterwards frying, which will give darker color due to Maillard reaction.

In the research a medium-close linear correlation ($r = -0.529$) is found between glucose content in raw – uncooked potatoes and the color parameter L^* of shallow fried potatoes (Fig. 2).

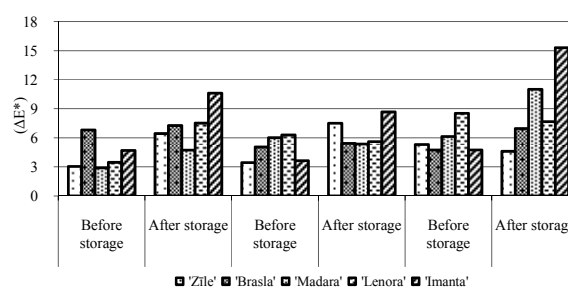


Fig. 1 Total color difference (ΔE^*) in five fried potato varieties by type of frying

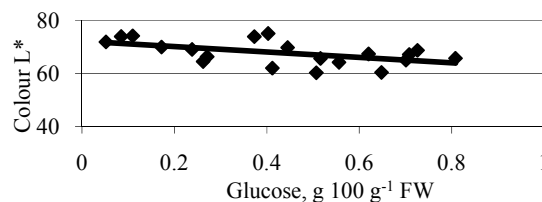


Fig. 2 Correlation between glucose content of fresh potatoes and color intensity in shallow fried potatoes

Correlation coefficient indicates slight tendency to decrease L^* (the crust of the shallow fried potatoes tends to be darker) in shallow fried potatoes if the initial glucose content in uncooked potatoes is higher.

The content of AA in the potatoes, evaluating it by the types of frying used in the research, using the potatoes either just after harvesting (non-stored) or using stored potatoes, is considerably different (Table IV).

TABLE IV
ACRYLAMIDE CONTENT OF THE STUDIED POTATOES

| Potato variety | 1 st study year | | 2 nd study year | |
|----------------|----------------------------|---------------|----------------------------|---------------|
| | Before storage | After storage | Before storage | After storage |
| | Roasted | | | |
| 'Zile' | 136.500±6.41 | 9.567±0.23 | 316.958±5.66 | 72.592±5.38 |
| 'Brasla' | 63.392±1.75 | 19.092±2.61 | 139.642±4.23 | 16.850±2.84 |
| 'Madara' | 87.875±1.40 | 110.592±5.59 | 115.650±0.86 | 281.017±24.77 |
| 'Lenora' | 68.275±2.33 | 273.367±8.39 | 280.867±8.08 | 71.658±2.90 |
| 'Imanta' | 26.100±2.73 | 132.517±5.49 | 170.192±5.33 | 33.533±11.89 |

| Shallow-fried / pan-fried | | | | |
|---------------------------|----------------|---------------|----------------|----------------|
| 'Zile' | 620.533±13.95 | 174.700±7.27 | 706.742±2.13 | 306.808±3.56 |
| 'Brasla' | 300.225±2.93 | 425.658±16.83 | 357.092±28.92 | 487.867±5.54 |
| 'Madara' | 468.892±9.52 | 519.717±21.19 | 305.958±6.82 | 434.675±6.57 |
| 'Lenora' | 182.275±1.44 | 804.208±11.00 | 317.642±2.19 | 679.108±7.30 |
| 'Imanta' | 156.183±4.99 | 339.967±7.17 | 730.150±14.85 | 366.133±9.80 |
| Deep-fat fried | | | | |
| 'Zile' | 170.242 ± 4.60 | 98.108±3.12 | 419.258±9.43 | 78.458±6.91 |
| 'Brasla' | 416.450±43.87 | 529.717±10.14 | 388.500±28.60 | 165.550±3.71 |
| 'Madara' | 405.792±13.61 | 267.175±15.33 | 1191.150±53.43 | 147.867±8.39 |
| 'Lenora' | 272.817±17.63 | 552.100±32.35 | 378.733±16.87 | 143.092±8.39 |
| 'Imanta' | 155.950±8.70 | 287.025±23.20 | 894.242±33.62 | 1324.417±31.54 |

The lowest content of AA is found in roasted potatoes – on average from 60–173µg kg⁻¹ fresh weight (FW), and its content in the fried potatoes of all the varieties which are fried after storage, has increased. The greatest difference between the potatoes fried just after harvesting and the potatoes fried after storage is found in the potato variety 'Zile'. In shallow fried potatoes the content of AA is in average within the range of 393–496µg kg⁻¹ FW, but in deep-fat fried potatoes it is 337–665µg kg⁻¹ FW.

The content of AA differs significantly by the type of frying used in the research ($p < 0.001$) and on average its content among roasted potatoes ($\mu = 121.31\mu\text{g kg}^{-1}$ FW), deep-fat fried potatoes ($\mu = 414.33\mu\text{g kg}^{-1}$ FW) and shallow fried ($\mu = 434.24\mu\text{g kg}^{-1}$ FW) varies widely.

Evaluating the content of AA in fried potatoes by the type of treatment, significant differences in AA content are found between roasted potatoes ($p = 0.011$) and deep-fat fried potatoes ($p = 0.004$) which are fried freshly harvested and fried and the potatoes which are fried after being stored. Similarly, in both above mentioned frying types, significant differences in AA content are found among the potato varieties (in the potato varieties after roasting ($p = 0.013$) and after deep-fat frying ($p = 0.004$).

A. Serpen et al. [15] have found moderate correlation ($r = 0,787$) between total color difference and AA content thus color value can be used for AA content prediction [15]. In the research correlation in AA with color factors a^* , L^* and ΔE^* has been found differently – depending on the type of frying (Table V). Correlation with AA and glucose was found only in roasted potatoes. In roasted potatoes correlation with AA was indicated between L^* while in shallow fried – a^* .

Correlation analysis (r) of acrylamide content with color and glucose in fried potatoes

TABLE V
CORRELATION ANALYSIS OF ACRYLAMIDE CONTENT WITH COLOR AND GLUCOSE IN FRIED POTATOES

| Parameter | Roasted | Shallow fried | Deep-fat fried |
|--------------|---------|---------------|----------------|
| a^* | w. cr.* | 0.53 | 0.78 |
| L^* | -0.56 | w. cr. | -0.58 |
| ΔE^* | w. cr. | w. cr. | 0.71 |
| Glucose | 0.58 | w. cr. | w. cr. |

* w. cr. – weak correlation

IV. CONCLUSION

The changes in the chemical composition of potatoes vary significantly according to the types of frying ($p < 0.05$), depending on the potato variety, harvest year and the type and

season (before or after storage) of frying. There are common tendencies in the changes of separate indices: in the case of roasted, shallow fried and deep-fat fried potatoes- the changes in the content of AA depend on the potato variety and storage; the changes in the content of glucose depends on the storage of potatoes. The content of AA in roasted potatoes is from 60 to 173µg kg⁻¹, in shallow fried potatoes from 393 to 496µg kg⁻¹, in deep-fat fried potatoes from 337 to 665µg kg⁻¹. In stored and fried potatoes considerably higher content of AA is found due to the biological processes taking place in potatoes during storage. The obtained results of the research indicate a medium close correlation between the content of AA and color values.

ACKNOWLEDGMENT

The authors acknowledge financial support from the following: project „Sustainable use of local agricultural resources for development of high nutritive value food products (Food)” within the National Research Programme “Sustainable use of local resources (earth, food, and transport) – new products and technologies (NatRes)” (2010.-2013.), ERAF Project „Promotion of scientific activities of LLU”, Contract Nr. 2010/0198/2DP/2.1.1.2.0/10/APIA/VIAA/020, Erasmus program and collaboration of Swedish National Food Administration, Chemistry Division 1. Special thanks for theoretical and technical assistance during AA analysis to B. Hellkvist, J. Rosen and K.-E. Hellenas.

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Research Programme “Sustainable use of local resources (earth, food, and transport) – new products and technologies (NatRes)” (2010.-2013.)

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