



Reducing Sugar Content and Colour Intensity of Fried Latvian Potato Varieties

Reducējošo cukuru saturs un krāsas intensitāte ceptos Latvijas šķirņu kartupeļos

Irisa Murniece, Daina Karklina, Ruta Galoburda, Martins Sabovics

Department of Food Technology, LLU

LLU Pārtikas tehnoloģijas katedra

e-mail: irisamurniece@yahoo.com

Abstract: The Maillard reaction between amino acids and reducing sugars is responsible for the development of colour and taste of fried potato products. The aim of the research was to evaluate the reducing sugars content and subsequently colour intensity of five Latvian potato varieties prepared by common frying methods used in Latvia. The research was carried out on five potato varieties ('Lenora', 'Brasla', 'Imanta', 'Zīle', and 'Madara') in two potato harvesting years (2007 and 2008) divided into two seasons: before storage (in autumn), and after a six-month storage (in spring) at 5 ± 1 °C and relative air humidity of $80\pm 5\%$. Potatoes were prepared by roasting in oven (210 ± 5 °C), shallow frying (150 ± 5 °C), and deep-fat frying (180 ± 5 °C). Total reducing sugars, fructose and glucose content as well as the colour ($L^* a^* b^*$) of fried potatoes were analyzed. The amount of total reducing sugars differed per each type of cooking method and potato variety. Glucose and fructose content was higher in potatoes stored for longer time. After storage the highest amount of glucose was observed in the potato variety 'Zīle' (i.e. 0.808 g 100 g⁻¹), whereas the highest amount of fructose was in 'Brasla' potatoes (i.e. 0.143 g 100 g⁻¹). The effect of storage and heat treatment on the colour formation and amount of reducing sugars differed per each potato variety.

Key words: potatoes, storage, frying, reducing sugars, colour.

Introduction

Potato is one of the world's major agricultural crops. It is consumed daily by millions of people from diverse cultural backgrounds and it is already an integral part of the global food system (International ..., 2008). From potato (*Solanum tuberosum* L.) harvest to consumption there are many factors that cause changes in chemical composition and, as a consequence, in nutritional value. Changes mainly occur during storage and culinary process (Burton, van Es, Hartmans, 1992). Storing of potato tubers at a low temperature is desirable because it inhibits sprouting and reduces the loss due to storage rot (Burton, Wilson, 1978), but low-temperature storage of potatoes, however, leads to an accumulation of sugars by a process that is called "low-temperature sweetening" (Burton, 1989; Sowokinos, 1990) where rapid conversion of starch to reducing sugars occurs (Smith, 1975).

On average, potatoes contain 19.4% of carbohydrates, mainly starch, and some sucrose, fructose and glucose within the range of 13.3–30.53%

(Pavlista, Ojala, 1997; Smith, 1975). Reducing sugars such as fructose and glucose in reaction with α -amino groups form dark colour and give a bitter taste to fried potatoes (Davies, Viola, 1992). The increased content of reducing sugars can contribute to development of darker colour, sweeter taste and soft texture in a fried product probably due to the low content of starch and increased content of reducing sugars (Adams, 2004). Optimum content of reducing sugars in potatoes is 0.1%, and it should not exceed 0.33% (Davies, Viola, 1992).

One of the oldest and commonly used cooking methods is frying because of taste, aroma and colour of the product (Simac-Brnčić, Lelas et al., 2004). The colour 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 (Scanlon, Roller et al., 1994). Fried potato colour is the result of Maillard, non-enzymatic browning reaction that depends on the superficial reducing sugars content, i.e. mainly glucose and

fructose, and the temperature as well as the frying period (Márquez, Añón, 1986) wherein heat and mass transfer phenomena take place during frying causing physicochemical changes which affect the colour of fried products (Krokida, Oreopolou et al., 2001; Pokorny, 1999).

The aim of the research was to evaluate reducing sugars content and subsequently colour intensity of five Latvian potato varieties prepared by common frying methods used in Latvia.

Materials and Methods

Potato tubers of five varieties (hereinafter in the text “potatoes”) – ‘Lenora’, ‘Brasla’, ‘Imanta’, ‘Madara’, and ‘Zīle’ – were bred, cultivated and stored at the State Priekuli Plant Breeding Institute. The size of the tubers was within the range of 4–6 cm, and average mass – 200±15 g. The research was carried out over a period of three years, analysing the potato samples in the autumn of 2007 and 2008 after the harvest, and in the spring of 2008 and 2009 after storing the respective year’s harvest in a cellar at 5±1 °C and relative humidity of 80±5%. The storage temperature was low therefore the potatoes before frying were stored for 1–2 weeks at the room temperature of 20±3 °C to promote reconditioning of carbohydrates in potatoes, thus diminishing the content of reducing sugars in the potatoes.

The potatoes were prepared using three types of frying: in an oven (potato to oil ratio – 1:0.009, at 210±5 °C), in a pan – in a small amount of oil (1:0.04, at 150±5 °C), and in a deep-fat fryer – in a high amount of oil (1:4.9, at 175±5 °C). For each frying method, the cutting or slicing methods were different: for shallow frying the potatoes were sliced into 0.7×1.0 and 3–4 cm long strips; for deep fat frying – into 0.6 × 0.6 and 4–5 cm long strips; and for baking in the oven the potatoes were cut horizontally into halves. Sunflower-seed oil “Floriol” was used for frying.

The potatoes were fried both before and after the storage, and afterwards were analysed for dry matter content by LVS ISO 6496:1999, for total reducing sugars and fructose (Somogyi, 1952), and for glucose content (Foreman, 2004).

The colour of potato samples was measured by “Color Tec-PCM” device (USA). For evaluation of the colour of uncooked potato samples, potato slices were cut shortly before measurement in order to avoid formation of melanin pigments in non-enzymatic browning reaction which can affect the accuracy of colour measurement. For evaluation of

the colour of fried potato samples, the product was homogenized, transferred to a Petri dish, and covered by a transparent PP film (“Forpus”), thickness of 25 µm, to avoid direct contact between the aperture of the measuring device and the product. The colour 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 colour was defined by three co-ordinates according to the CIE (*Commission Internationale de l’Eclairage*) lab system: 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) (Coulter, 2002). For evaluation of colour change, the total colour difference (TCD), ΔE^* , was calculated between measurements in fresh and fried samples (Serpen, Gökmen, 2009; Mafalda Quintas, Teresa Brandão, Cristiana Silva, 2007) according to equation (1):

$$\Delta E^* = \sqrt{(L^* - L^*_0)^2 + (a^* - a^*_0)^2 + (b^* - b^*_0)^2}, \quad (1)$$

where

L^* , a^* , b^* – value measured in an uncooked potato sample;

L^*_0 , a^*_0 , b^*_0 – value measured in a fried potato sample.

For mathematical data processing, the following tests and analyses were used: one-factor and two-factor dispersion analyses (ANOVA), Tukey’s test, correlation and regression analysis, as well as least squares method (Arhipova, Bāliņa, 2003).

To compare the obtained results of chemical analyses for non-fried and differently fried potatoes, recalculation was carried out from g 100 g⁻¹ of fresh weight (FW) per g 100 g⁻¹ of dry weight (DW). The results expressed per DW allow comparing changes in a particular compound between differently cooked potatoes, whereas FW was used to compare the results of our research with those published in the literature. The results represent the mean value and standard deviation from both harvest years of the potatoes. The proposed hypotheses were tested with the p-value method, and the factors were evaluated as substantial if p -value < α = 0.05. It was assumed that α = 0.05 at 95% confidence.

Results and Discussion

The content of reducing sugars, glucose, and fructose in raw potatoes

Before potato storage, in the analysed potato varieties the **total content of reducing sugars** in 100 g of DW is within the range of 0.25 g ('Zīle') to 3.27 g ('Lenora'), and after storage – 1.85 g ('Madara') – 3.89 g ('Zīle'). In the researched potato varieties the content of reducing sugars after storage has increased. In the analysed potato varieties, before storage, the **total content of reducing sugars** in 100 g of DW varied from 0.25 g ('Zīle') to 3.27 g ('Lenora'), but after storage it increased and varied from 1.85 g ('Madara') to 3.89 g ('Zīle'). Our results agree with the results obtained in other scientists' research on potatoes (Gichohi, Pritchard, 1995; Storey, Davies, 1992; Burton, 1989). The increase in the content of reducing sugars can be explained not only by the mutual influence between sugars and starch at low storage temperature, but also by physiological ageing of the potato tubers and the beginning of the sprouting process (Storey, Davies, 1992; Orr, Sacks, 1992; Hertog, Putz, Tijsskens, 1997).

In the research, the total content of reducing sugars in potatoes after storage, in comparison to their content in potatoes analysed just after harvesting, had increased 1.78 times on average (Table 1).

The results obtained by data analysis indicate significant differences in the mean values of the content of reducing sugars in potatoes before and after the storage ($p=0.008$).

The high standard deviation can be explained by the substantial differences between the results obtained on researched potatoes in the harvest years 2007 and 2008.

The content of total reducing sugars in 100 g of FW varied: before storage – from 0.06 g ('Zīle') to 0.69 g ('Brasla'), and after storage – from 0.48 g ('Madara') to 0.90 g ('Zīle'). In the study of A. Kita (2002) on five varieties of potatoes grown in Poland and analyzed shortly after harvesting, the total reducing sugars content was from 0.012 g to 0.127 g 100 g⁻¹ of FW.

Significant differences were determined in the content of reducing sugars, which can have several explanations: in a potato tuber during its formation monosaccharides are deposited as a result of photosynthesis, and are further re-synthesized in polysaccharide – starch (Pritchard, Adam, 1994; Burton, van Es, Hartmans, 1992). The shorter the days during potato growing, the more sugars are

accumulated – passive re-synthesis of sugars into starch occurs (Beukema, Van der Zaag, 1979). V. Buono et al. have detected higher content of total reducing sugars in potatoes of several varieties grown in 2007 in the Southern Italy (Buono, Paradiso, Sero et al., 2009). Three potato varieties were used in the study, and the content of total reducing sugars was within the range of 0.465 g to 1.041 g 100 g⁻¹ of FW. It was mentioned that potatoes having the highest content of reducing sugars had the lowest content of starch. The above described interconnections allow drawing a conclusion that potatoes with a high content of starch and low content of reducing sugars are fully mature. It should be mentioned that in potatoes total reducing sugars are mainly formed by glucose and fructose (Haase, 2006), dominated by glucose.

The researched **glucose content** in 100 g of DW, before storage (in autumn), was within the range of 0.21–2.60 g, but after storage – 1.44–3.49 g. In autumn, glucose content in potatoes was lower than in spring after storing, and its content on average had increased 2.2 times (Table 2). The data obtained by statistical analysis also show significant differences in glucose content between the freshly harvested potatoes and those which were stored ($p=0.002$). The increase in glucose content in the stored potatoes can be explained by splitting of starch and sucrose into monomers during storage.

The glucose content in 100 g of FW of freshly harvested potatoes varied from 0.052 g ('Zīle') to 0.516 g ('Brasla'), and after storage – from 0.373 g ('Madara') to 0.808 g ('Zīle'). It is not possible to compare our data with the results of E. Finotti's et al. research (the glucose content in nine varieties of potatoes grown in Bologna area, Italy, was between 0.02 g and 0.34 g 100 g⁻¹ of FW), because the researchers give no sufficiently detailed information on the studied potatoes – it is only mentioned that the potatoes were stored at the temperature of 4 °C (Finotti, Bertone, Vivanti, 2006).

Fructose content in 100 g of DW of potatoes was within the range of 0.03 g ('Zīle') to 0.68 g ('Lenora'). In freshly harvested potatoes, the fructose content on average was 0.23 g, and after storage – 0.22 g (Table 3). Fructose is the second prevailing reducing sugar in potatoes, and it can be formed as a result of sucrose hydrolysis when potatoes are stored at low temperature (Burton, van Es, Hartmans, 1992). Significant differences in fructose content were observed by harvest years ($p=0.006$).

Table 1

The content of reducing sugars in potatoes before and after storage, g 100 g⁻¹ of DW

Potato variety	Before storage, average±SD	After storage, average±SD	The whole period, $x_{\min} - x_{\max}$
‘Zīle’	0.85±0.85	3.29±0.85	0.25–3.89
‘Brasla’	1.68±1.80	1.91±0.10	0.41–2.95
‘Madara’	1.34±0.39	2.54±0.97	1.07–3.23
‘Lenora’	2.76±0.72	3.21±0.79	2.25–3.77
‘Imanta’	0.88±0.47	2.86±0.42	0.55–3.15
Total	1.50	2.76	0.25–3.89

Table 2

The content of glucose in potatoes before and after storage, g 100 g⁻¹ of DW

Potato variety	Before storage, average±SD	After storage, average±SD	The whole period, $x_{\min} - x_{\max}$
‘Zīle’	0.78±0.80	2.99±0.70	0.21–3.49
‘Brasla’	1.27±1.33	1.61±0.15	0.33–2.21
‘Madara’	1.09±0.42	2.28±1.18	0.79–3.11
‘Lenora’	2.31±0.41	2.86±0.40	2.03–3.14
‘Imanta’	0.71±0.37	2.56±0.55	0.45–2.95
Total	1.23	2.74	0.21–3.49

Table 3

The content of fructose in potatoes before and after storage, g 100 g⁻¹ of DW

Potato variety	Before storage, average±SD	After storage, average±SD	The whole period, $x_{\min} - x_{\max}$
‘Zīle’	0.07±0.05	0.21±0.21	0.03–0.49
‘Brasla’	0.27±0.26	0.24±0.24	0.08–0.53
‘Madara’	0.22±0.00	0.15±0.15	0.11–0.32
‘Lenora’	0.45±0.33	0.39±0.39	0.09–0.68
‘Imanta’	0.14±0.14	0.12±0.12	0.04–0.39
Total	0.23	0.22	0.03–0.68

The content of reducing sugars in fried potatoes depending on storage and type of frying

It was determined that **total reducing sugars** in 100 g of FW of fried potatoes depending on the type of frying varied: in roasted potatoes – from 0.18±0.00 g (‘Zīle’, autumn 2008) to 1.29±0.01 g of FW (‘Lenora’, spring 2008, after storage); in shallow fried potatoes – from 0.12±0.00 g (‘Zīle’, autumn 2008) to 1.10±0.01 g of FW (‘Lenora’, spring 2008); and in deep-fat fried potatoes – from 0.14±0.00 g (‘Brasla’, autumn 2008) to 1.32±0.00 g of FW (‘Zīle’, autumn 2008).

The total content of reducing sugars in 100 g of DW was: in roasted potatoes – from 0.49 g (‘Zīle’, spring 2008, after storage) to 3.75 g (‘Zīle’, autumn 2008, before storage); in shallow fried potatoes – from 0.30 g (‘Zīle’) to 3.95 g (‘Lenora’); and in deep-fat fried potatoes – from 0.22 g (‘Brasla’) to 2.90 g (‘Zīle’) (Table 4). In spring, after storing the potatoes, the content of reducing sugars in roasted potatoes was higher than in the potatoes roasted in autumn.

Also after the statistical processing of data, the obtained results indicated substantial differences in reducing sugar content in the researched

Table 4

The content of reducing sugars in fried potatoes, g 100 g⁻¹ of DW

Type of treatment	Potato variety	Before storage, average±SD	After storage, average±SD	Before and after storage, $x_{\min} - x_{\max}$
Roasted	'Zīle'	1.20±0.04	2.92±0.04	0.49–3.75
	'Brasla'	1.59±0.03	2.04±0.01	0.58–2.61
	'Madara'	1.65±0.02	3.12±0.11	1.19–3.58
	'Lenora'	3.28±0.02	3.43±0.04	2.91–3.71
	'Imanta'	1.86±0.10	2.56±0.04	1.33–3.05
	Total	1.92	2.81	0.49–3.75
Shallow fried	'Zīle'	0.85±0.06	2.49±0.13	0.30–3.07
	'Brasla'	1.31±0.04	1.62±0.08	0.41–2.21
	'Madara'	1.30±0.03	1.53±0.06	0.86–2.20
	'Lenora'	2.14±0.01	3.48±0.10	1.64–3.95
	'Imanta'	0.95±0.03	2.08±0.10	0.43–2.20
	Total	1.31	2.24	0.30–3.95
Deep-fat fried	'Zīle'	0.67±0.02	1.71±0.01	0.32–2.90
	'Brasla'	0.94±0.02	0.97±0.05	0.22–1.65
	'Madara'	0.81±0.01	1.08±0.03	0.60–1.20
	'Lenora'	1.47±0.02	2.22±0.07	1.44–2.38
	'Imanta'	0.76±0.04	1.88±0.12	0.56–2.75
	Total	0.93	1.57	0.22–2.90

Table 5

Significance level of the reducing sugar content in fried potatoes by type of cooking

Roasted	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.052
	Year	1st harvesting year			2nd harvesting year		p=0.712
	Period	a* Before storage			b* After storage		p=0.025
Shallow fried	Variety	a 'Zīle'	a 'Brasla'	a 'Madara'	b 'Lenora'	ab 'Imanta'	p=0.013
	Year	1st harvesting year			2nd harvesting year		p=0.551
	Period	a Before storage			b After storage		p=0.027
Deep-fat fried	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.094
	Year	1st harvesting year			2nd harvesting year		p=0.074
	Period	a Before storage			b After storage		p=0.020

* – values, marked with the same letter, are not significantly different ($p > \alpha_{0.05}$).

varieties ($p < 0.001$) and by the types of frying ($p < 0.001$). Evaluating the content of reducing sugars in fried potatoes by the types of treatment (Table 5), the reducing sugars content in roasted potatoes differed substantially from that of freshly harvested

and stored potatoes ($p = 0.025$), in shallow fried potatoes – also between freshly harvested and stored potatoes ($p = 0.027$) and among the researched varieties ($p = 0.013$), and in deep-fat fried potatoes – among freshly harvested and stored potatoes ($p = 0.020$).

Table 6

The content of glucose in fried potatoes, g 100 g⁻¹ of DW

Type of treatment	Potato variety	Before storage, average±SD	After storage, average±SD	Before and after storage, $X_{min}-X_{max}$
Roasted	'Zīle'	1.09±0.03	2.42±0.05	0.43–3.16
	'Brasla'	1.34±0.18	1.49±0.02	0.49–2.19
	'Madara'	1.20±0.07	2.63±0.27	0.98–3.31
	'Lenora'	2.83±0.05	2.81±0.15	2.55–3.10
	'Imanta'	1.40±0.08	2.13±0.05	0.77–2.69
	Total	1.57	2.29	0.43–3.31
Shallow fried	'Zīle'	0.68±0.03	2.18±0.07	0.26–2.65
	'Brasla'	1.06±0.06	1.33±0.03	0.28–1.84
	'Madara'	1.14±0.03	1.34±0.01	0.66–2.01
	'Lenora'	1.81±0.05	2.85±0.13	1.53–3.02
	'Imanta'	0.71±0.02	1.84±0.06	0.26–1.86
	Total	1.08	1.91	0.26–3.02
Deep-fat fried	'Zīle'	0.53±0.02	1.37±0.06	0.29–2.35
	'Brasla'	0.77±0.02	0.74±0.02	0.17–1.36
	'Madara'	0.63±0.02	0.85±0.03	0.52–0.89
	'Lenora'	1.27±0.02	1.81±0.16	1.18–1.97
	'Imanta'	0.51±0.04	1.52±0.02	0.28–2.14
	Total	0.74	1.26	0.17–2.35

During the frying process, with the increase of environment temperature, different chemical changes take place, and one of these changes is the Maillard reaction (Dale, Mackay, 1994; Burton, van Es, Hartmans, 1992).

It was determined that **glucose content** in 100 g of fried potatoes depending on the type of frying varied: in roasted potatoes – from 0.16±0.01 g ('Zīle', autumn 2008) to 1.04±0.13 g ('Madara', spring 2009); in shallow fried potatoes – from 0.11±0.01 g ('Zīle', autumn 2008) to 0.90±0.03 g ('Zīle', spring 2008); and in deep-fat fried potatoes – from 0.11±0.00 g ('Brasla', autumn 2008) to 1.07±0.04 g ('Zīle', spring 2008).

When glucose content was recalculated to 100 g of dry weight, the average results of the two-year study varied: in roasted potatoes – from 0.43 g ('Zīle') to 3.31 g ('Madara'); in shallow fried potatoes – from 0.26 g ('Zīle' and 'Madara') to 3.02 g ('Madara'); and in deep-fat fried potatoes – from 0.17 g ('Brasla') to 2.35 g ('Zīle') (Table 6).

The results obtained after analysis of the research data indicated a significant difference in the content of glucose (the same as in the content of total reducing sugars) among the varieties used in the

research ($p=0.003$), as well as among the types of heat treatment ($p<0.001$). Evaluation of the content of glucose by types of treatment (Table 7) showed significant differences between shallow fried potatoes – freshly harvested fried potatoes and those fried in spring after storage ($p=0.008$).

Fructose is the second prevailing reducing sugar in potatoes (Burton, van Es, Hartmans, 1992). **Fructose content** in the researched fried potatoes in 100 g of product is the following: the lowest content is observed in potatoes of variety 'Zīle' fired by any researched type of frying in autumn 2009. The lowest **fructose content** in 100 g of the researched fried potatoes was observed in potatoes of variety 'Zīle' fried by any researched type of frying in autumn of the year 2009. In roasted potatoes the fructose content varied from 0.018±0.002 g to 0.213±0.047 g ('Imanta', spring 2008); in shallow fried potatoes – from 0.016±0.001 g to 0.193±0.016 g ('Lenora', spring 2008); and in deep-fat fried potatoes – from 0.022±0.005 g to 0.259±0.013 g ('Zīle', spring 2008).

In the dry weight of roasted potatoes, fructose content varied from 0.05 g ('Zīle') to 0.63 g 100 g⁻¹ of DW ('Madara' and 'Lenora'); in shallow

Table 7

Significance level of the glucose content in fried potatoes by type of cooking

	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.169	
Roasted	Year	1st harvesting year			2nd harvesting year			p=0.784
	Period	Before storage			After storage			p=0.053
	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.090	
Shallow fried	Year	1st harvesting year			2nd harvesting year			p=0.765
	Period	a* Before storage			b* After storage			p=0.008
	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.327	
Deep-fat fried	Year	1st harvesting year			2nd harvesting year			p=0.093
	Period	Before storage			After storage			p=0.064

* – values, marked with the same letter, are not significantly different ($p > \alpha_{0.05}$).

Table 8

The content of fructose in fried potatoes, g 100 g⁻¹ of DW

Type of treatment	Potato variety	Before storage, average±SD	After storage, average±SD	Before and after storage, $x_{\min} - x_{\max}$
Roasted	'Zīle'	0.10±0.01	0.50±0.05	0.05–0.58
	'Brasla'	0.21±0.03	0.49±0.02	0.08–0.55
	'Madara'	0.43±0.03	0.40±0.04	0.24–0.63
	'Lenora'	0.49±0.04	0.54±0.04	0.36–0.63
	'Imanta'	0.45±0.04	0.43±0.06	0.37–0.52
	Total		0.34	0.47
Shallow fried	'Zīle'	0.15±0.02	0.31±0.04	0.04–0.42
	'Brasla'	0.22±0.01	0.30±0.03	0.11–0.39
	'Madara'	0.15±0.03	0.23±0.02	0.11–0.24
	'Lenora'	0.32±0.02	0.50±0.03	0.11–0.70
	'Imanta'	0.23±0.03	0.30±0.04	0.17–0.34
	Total		0.22	0.33
Deep-fat fried	'Zīle'	0.11±0.02	0.35±0.02	0.04–0.57
	'Brasla'	0.17±0.01	0.21±0.03	0.05–0.36
	'Madara'	0.18±0.02	0.22±0.02	0.09–0.27
	'Lenora'	0.18±0.01	0.30±0.05	0.11–0.50
	'Imanta'	0.24±0.03	0.33±0.01	0.15–0.51
	Total		0.17	0.28

fried potatoes – from 0.04 g ('Zīle') to 0.70 g 100 g⁻¹ of DW ('Lenora'); and in deep-fat fried potatoes similarly to shallow fried potatoes – from 0.04 g ('Zīle', before storage) to 0.57 g ('Zīle', after storage) (Table 8).

The differences in fructose content in fried potatoes, comparing freshly harvested fried potatoes with those fried after storage, were significant among the types of treatment ($p=0.002$): in roasted

Table 9

Significance level of the fructose content in fried potatoes by type of cooking

	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.413
Roasted	Year	a* 1st harvesting year			b* 2nd harvesting year		p=0.011
	Period	Before storage			After storage		p=0.080
	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.166
Shallow fried	Year	a 1st harvesting year			b 2nd harvesting year		p=0.008
	Period	Before storage			After storage		p=0.086
	Variety	'Zīle'	'Brasla'	'Madara'	'Lenora'	'Imanta'	p=0.927
Deep-fat fried	Year	a 1st harvesting year			b 2nd harvesting year		p=0.000
	Period	Before storage			After storage		p=0.156

* – values, marked with the same letter, are not significantly different ($p > \alpha_{0.05}$).

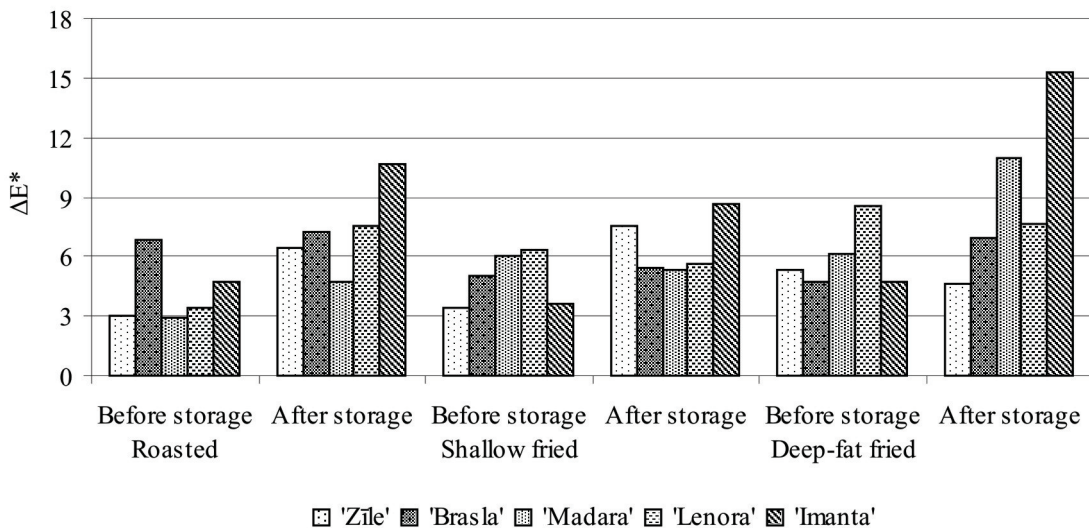


Fig. 1. The total colour difference, ΔE^* , in five fried potato varieties per type of heat treatment.

potatoes $p=0.011$, in shallow-fried potatoes – $p=0.008$, and in deep-fried potatoes – $p<0.001$ (Table 9).

The colour of fried potatoes in the CIE L*a*b* system

The colour is one of factors showing intensity of the Maillard reaction (Mestdagh, Wilde et al., 2008; Gökmen, Akbudak et al., 2007; Pedreschi, Moyano et al., 2005). A. Serpen and V. Gökmen (2009) have established moderate correlation ($r=0.787$) between total colour difference and acrylamide content, which allows using colour value for acrylamide content

prediction. Darker colour of fried starch-based products indicates a higher content of acrylamide. The fried potatoes of the variety 'Imanta' (Fig. 1) had a pronounced difference in total colour intensity (ΔE^*), which indicates the likelihood of a higher content of acrylamide in this particular variety. Total colour difference in potatoes of variety 'Imanta' was significantly different from other potato varieties.

In shallow fried potatoes, the less pronounced colour intensity difference was observed in potatoes of variety 'Lenora', whereas in deep-fat fried potatoes – in 'Imanta' potatoes, which indicates that crust colour of these potatoes was darker compared

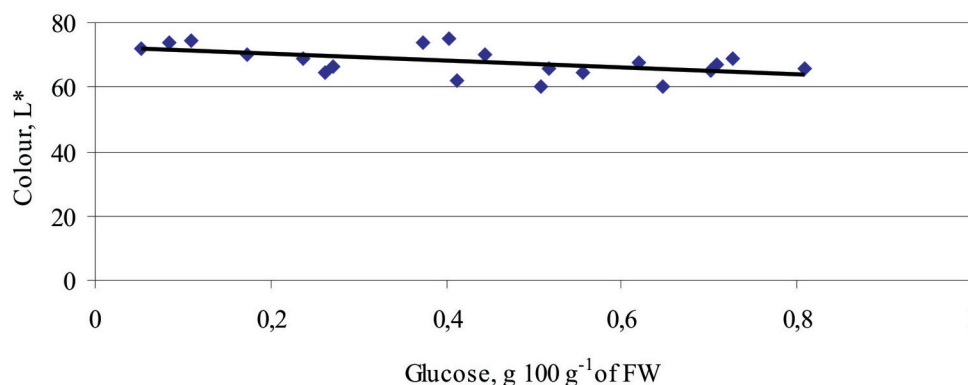


Fig. 2. The correlation between glucose content of fresh potatoes and colour intensity in shallow fried potatoes.

to potatoes of other varieties and that most intensive colour was found in potatoes that were fried after storage. A significant total colour difference was found in potatoes which were roasted before and after storage ($p=0.034$) whereas no significant colour differences were found in shallow fried and deep-fat fried potatoes.

In potatoes the main reducing sugar is glucose therefore it mainly influences the intensity of the colour of fried potatoes. In our research, a medium-close linear correlation ($r=-0.529$) was found between the glucose content of raw (uncooked) potatoes and the colour parameter L^* of shallow fried potatoes (Fig. 2). The correlation coefficient indicates that the colour parameter L^* tends to decrease slightly (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 statistical analysis showed significant ΔE^* differences in the colour of fried potatoes if frying freshly harvested or stored potatoes. It can be explained by the increase of reducing sugars content when potatoes are stored at low temperature and afterwards fried, which gives darker colour due to Maillard reaction.

Conclusions

The research demonstrated significant changes in the content of reducing sugars ($p=0.008$), glucose ($p=0.002$), fructose ($p=0.006$), and sucrose ($p=0.007$) of potatoes after storage. Significant differences in the total reducing sugar content were determined in shallow fried potato variety 'Lenora' compared to 'Zīle', 'Brasla', and 'Madara' potatoes.

The content of reducing sugars changed in the frying process and differed by the type of treatment: in

autumn it increased by 28% in roasted potatoes (prior and after the storage $p=0.025$), decreased by 12.6% in shallow fried potatoes (by variety $p=0.013$; prior and after the storage $p=0.027$), and decreased by 38% in deep-fat fried potatoes (before and after the storage $p=0.020$); but in spring it increased by 2% in roasted potatoes, decreased by 19% in shallow fried potatoes, and decreased by 43% in deep-fat fried potatoes.

A medium close linear correlation was found between glucose content of uncooked potatoes and the colour parameter L^* of shallow fried potatoes ($r=-0.529$).

References

1. Adams, J.B. (2004) Raw materials quality and the texture of processed vegetables. *Texture in Foods*. Vol. 2: Solid Foods. Ed. D. Kilcast. Cambridge, Woodhead Publ. Ltd, 342–363.
2. Arhipova, I., Bāliņa, S. (2003) *Statistika ekonomikā. Risinājumi ar SSPS un Microsoft Excel*. Mācību līdzeklis. Rīga, Datorzinību centrs, 352 lpp.
3. Beukema, H.P., van der Zaag, D.E. (1979) *Potato improvement, some factors and facts*. International agricultural centre, Wageningen, the Netherlands, 250 pp.
4. Buono, V., Paradiso, A., Sero, F., Gonnella, M., Gara, L., Santamaria, P. (2009) Tuber quality and nutritional components of „early” potato subjected to chemical haulm desiccation. *Journal of Food Composition and Analysis*, No. 22, 556–562.
5. Burton, W.G. (1989) *The Potato*. 3rd ed. New York, Longman Scientific & Technical, 286–522.

6. Burton, W.G., van Es, A., Hartmans, K.J. (1992) The physics and physiology of storage. *The Potato Crop*. London, Chapman and Hall, 608–727.
7. Burton, W.G., Wilson, A.R., (1978) The sugar content and sprout growth of tubers of potato cultivar Record, grown in different localities, when stored at 10, 2 and 20 °C. *Potato Research*, No. 21, 145–162.
8. Coultate, T. P. (2002) Food: the chemistry of its components. Cambridge, UK, RSC Paperbacks, 213–217.
9. Dale, M.F.B., Mackay, G.R. (1994) Inheritance of table and processing quality. *Potato Genetics*. Wallingford, CAB International, 285–307.
10. Davies, H. V., Viola, R. (1992) Regulation of sugar accumulation in stored potato tubers. *Postharvest News Inf.*, No. 3, Issue 5, 97–100.
11. Finotti, E., Bertone, A., Vivanti, V. (2006) Balance between nutrients and anti-nutrients in nine Italian potato cultivars. *Food Chemistry*, No. 99, 698–701.
12. Foreman, D., Gaylor, L., Evans, E., Trella, C. (2004) A modification of the Roe procedure for determination of fructose in tissues with increased specificity. *Analytical Biochemistry*, Vol. 56 (2), 584–590.
13. Gichohi, E.G., Pritchard, M.K. (1995) Storage temperature and maleic hydrazide effects on sprouting, sugars and fry color of ‘Shepody’ potatoes. *American Potato Journal*, No. 72, 737–747.
14. Gökmen, V., Akbudak, B., Serpen, A., Acar, J., Turan, Z.M., Eriş, A. (2007) Effects of controlled atmosphere storage and low-dose irradiation on potato tuber components affecting acrylamide and color formations upon frying. *European Food Research and Technology*, No. 224, 681–687.
15. Haase, N.U. (2006) The formation of acrylamide in potato products. Eds K. Skog, J. Alexander. *Acrylamide and Other Hazardous Compounds in Heat-treated Foods*. Cambridge, England, Woodhead publishing limited, 41–59.
16. Hertog, M.L.A.T.M., Putz, B., Tijssens, L.M.M. (1997) The effect of harvest time on the accumulation of reducing sugars during storage of potatoes (*Solanum tuberosum L.*) tubers: experimental data described, using a physiological based mathematical model. *Potato Research*, No. 40, 69–78.
17. *International Year of Potato 2008. New lights on a hidden treasure.* (2008) An end-of-year review. Food and Agriculture Organisation of the United Nation, Rome, 148 pp.
18. Kita, A. (2002) The influence of potato Chemical composition on crisp texture. *Food Chemistry*, No. 76, 173–179.
19. Krokida, M.K., Oreopolou, V., Maroulis, Z.B., Marinos-Kouris, D. (2001) Colour changes during deep fat frying. *Journal of Food Engineering*, No. 49, 219–225.
20. Mafalda, A.C. Quintas, Teresa, R.S. Brandão, Cristiana, L.M. Silva (2007) Modelling colour changes during the caramelisation reaction. *Journal of Food Engineering*, No. 83, 483–491.
21. Márquez, G., Añón, M. C. (1986) Influence of reducing sugars and amino acids in the color development of fried potatoes. *Journal of Food Science*, Vol. 51, Issue 1, 157–160.
22. Mestdagh, F., Wilde, T.D., Castelein, P., Nemeth, O., Peteghem, C.V., Meulenaer, B.D. (2008) Impact of the reducing sugars on the relationship between acrylamide and Maillard browning in French fries. *European Food Research and Technology*, No. 227, 69–76.
23. Orr, P.H., Sacks, J.M. (1992) Chipping responses of stored potatoes after handling. *Transaction of the ASAE (USA)*, No. 35, vol.3, 967–968.
24. Pavlista, A.D., Ojala, J.C. (1997) Potatoes: chip and French fries processing. *Processing Vegetables: Science and Technology*. Eds D.S. Smith, J.N. Cash, W.K. Nip, Y.H. Hui. USA, Technomic Publishing Company, 237–284.
25. Pedreschi, F., Moyano, P., Kaack, K., Granby, K. (2005) Color changes and acrylamide formation in fried potato slices. *Food Research International*, No. 38, 1–9.
26. Pokorný, J. (1999) Changes of nutrients at frying temperatures. *Frying of Food*. Eds D. Boskou, I. Elmadfa. Lancaster, Technomic Publishing, 75–76.
27. Pritchard, M.K., Adam, L.R. (1994) Relationships between fry color and sugar concentration in stored ‘Russet Burbank’ and ‘Shepody’ potatoes. *American Potato Journal*, No. 71, 59–68.
28. Scanlon, M.G., Roller, R., Mazza, G., Pritchard, M.K. (1994) Computerized video image analysis to quantify colour of potato chips. *American Potato Journal*, No. 71, 717–733.
29. Serpen, A., Gökmen, V. (2009) Evaluation of Maillard reaction in potato crisps by

- acrylamide, antioxidant capacity and color. *Journal of Food Composition and Analysis*, No. 22, 589–595.
30. Simac-Brnčić, S., Lelas, V., Rade, D., Šimundić, B. (2004) Decreasing of oil absorption in potato strips during deep fat frying. *Journal of Food Engineering*, No. 64, 237–241.
31. Smith, O. (1975) Potato chips. *Potato processing*. Eds W.F. Talburt, O. Smith. Westport, CT, The Avi Publishing Company, Inc., 305–402.
32. Somogyi, M. (1952) Notes on sugar determination. *Journal of Biology and Chemistry*, Vol. 195, 19–23.
33. Sowokinos, J.S. (1990) Stress-induced alteration in carbohydrate metabolism. *The Molecular and Cellular Biology of the Potato*. Eds M. E. Vayda, W. D. Park. Wallingford, CAB International, 137–158.
34. Storey, R.M.J., Davies, H.V. (1992) Tuber quality. *The Potato Crop*. London, Chapman and Hall, 507–568.

Acknowledgments

This research was supported by the ESF grant (contract JD35) and Latvian State Research Program No. 08-VP-9-9 in agrobiotechnology.

Anotācija

Ceptu kartupeļu krāsu un garšu ietekmē Maijāra reakcijas norise starp reducējošiem cukuriem un aminoskābēm. Pētījuma mērķis bija noteikt reducējošo cukuru saturu un ietekmi uz krāsas intensitāti piecu Latvijas šķirņu kartupeļos, kurus pagatavoja, izmantojot tradicionālos cepšanas veidus. Pētījumam izmantoja 'Lenora', 'Brasla', 'Imanta', 'Zīle' un 'Madara' šķirņu kartupeļus, un to veica divos ražas gados (2007. un 2008. gadā) pirms un pēc kartupeļu uzglabāšanas. Kartupeļus uzglabāja sešus mēnešus 5 ± 1 °C temperatūrā ar relatīvo gaisa mitrumu $80\pm 5\%$ un pēc tam cepa cepeškrāsnī (210 ± 5 °C), uz pannas (150 ± 5 °C) un fritūrā (180 ± 5 °C). Svaigos un ceptos kartupeļos noteica kopējo reducējošo cukuru daudzumu, fruktozes un glikozes saturu, kā arī krāsu ($L^* a^* b^*$). Reducējošo cukuru saturs bija atšķirīgs gan pa apstrādes veidiem, gan arī pa šķirnēm. Glikozes un fruktozes saturs augstāks bija uzglabātajos kartupeļos. Augstākais glikozes saturs pēc uzglabāšanas bija šķirnes 'Zīle' kartupeļos (0.808 g 100 g⁻¹), bet augstākais fruktozes saturs – šķirnes 'Brasla' kartupeļos (0.143 g 100 g⁻¹). Krāsas intensitāte un reducējošo cukuru saturs atkarībā no uzglabāšanas un termiskās apstrādes veida atšķīrās pa kartupeļu šķirnēm.