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ORIGINAL ARTICLE

The influence of edible coatings and natural antioxidants on fresh-cut potato quality, stability and oil uptake after deep fat frying

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Abstract The effect of four edible hydrocolloid coatings (carboxymethyl cellulose, chitosan, pectin and gum arabic) on fresh-cut potato's colour, pH and moisture content during storage was studied. Possibility of coating enrichment with natural olive leaf extract and sodium ascorbate was also evaluated. Coatings scored as the best ones straight after coating or during storage for 7 days at 10 ± 1 °C, were used for deep fat frying of potato. Chitosan was shown to cause significant decrease in pH and browning of potato strips. Pectin was classified as good coating alone but in combination with olive leaf extract showed lower quality parameters of fresh-cut samples compared to control. Only carboxymethyl cellulose and gum arabic itself or enriched with olive leaf extract or sodium ascorbate were shown not to affect colour, pH and moisture during storage. Moreover, these coatings significantly reduced fat content in deep fat fried potato strips, without influence on *L**, *b**, whiteness index *(WI)*, and *ΔE*.

Keywords Fresh-cut potato · Qality · Storage · Edible coatings · Olive leaf extract · Fat content

Introduction

Potatoes (*Solanum tuberosum* L.) are fourth most consumed crop in the world and its products are often thought of as a comfort food. French fries and chips are two most popular potato products within consumers because of their pleasant taste and typical flavour. They are produced by frying, a common and old technique of food processing that gives pleasant organoleptic but low nutritional product profile (Oke et al. 2018). Frying is described as a complex process including heat transfer and mass transport mechanisms such as surface browning, rapid water evaporation and oil absorption or degradation (Moreira et al. 1999). Fried food is generally rich in calories arising a concerning issue among healthy conscious consumers. Thus, scientists are continuously trying to develop novel processing tools in order to decrease the fat content in fried product, to reduce the quantity of formed acrylamide and free *trans* fatty acids without influencing specific organoleptic properties of fried food.

Minimally processed or fresh-cut fruits and vegetables, known as *ready-to-eat* or *ready-to-cook*, consider any type of fruits or vegetables that has been physically processed in comparison to harvested product (peeled, washed, cut) while maintaining fresh and non-processed state (Olivas 2007). Transformation methods (chemical, physical, non-thermal and edible films) are mostly aimed to reduce browning (inactivation of polyphenol oxidase) that results from mechanical stress used during handling (Ma et al. 2017). Recently, natural hydrocolloids have attracted an increasing attention due to the possible delay of changes that caused unacceptability of potatoes for further processing and use (Eça et al. 2014; Kurek et al. 2017). Spanou and Giannouli (2013) found that ascorbic acid and green tea extract in alginate/carboxymethyl cellulose

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coating improved shelf-life of fresh-cut potato owing to increased antioxidant capacity and decreased dehydration of cut potatoes. By applying edible coatings that have desirable barrier properties to gas/moisture and good mechanical characteristics, it is possible to reduce the water vapour transfer, which consequently results in lowering the oil uptake in the tissue during frying. Since the surface properties of foods affect the oil absorption during frying, coatings make the surface stronger and more compact, with fewer pores (Jia et al. 2017). This is a consequence of thermal gelation and polymerisation of polymer chains that fills the free space on the potato surface.

In order to improve functionality of coatings, existing studies are focused on antioxidants that are added to different formulations. There is also increasing interest in using natural antioxidants extracted from food wasted biomass, as by-products from food industry. Olive leaf (*Olea europea* L.) is rich in phenolic compounds with highest content of oleuropein (in water extract around 73%), a compound classified in group called secoiridoids (Talhaoui et al. 2015). Previously, this type of extract was also added to frying oil in order to improve the oxidative stability and antioxidant properties during frying (Talhaoui et al. 2015).

Bioactive extracts can be prepared using conventional or modern technologies, the later ones are most likely used nowadays due to its ecologically acceptable character and following principles of green chemistry. Ultrasound assisted extraction is considered as simple, efficient and cheap alternative to conventional extraction methods (Ahmad-Qasem et al. 2013). Research made on ultrasound assisted extraction of oleuropein and similar bio-phenols from olive leaf, found that ultrasound speeds up the extraction and due to the cavitation phenomenon it was more useful method compared to maceration (Khemakhem et al. 2017).

Chemical and physical interactions between edible polymer and incorporated extracts might influence their structure and functionality. Changes depend on the nature and structural changes of principal components (stereochemistry, conformational flexibility and molecular weight), chemical properties, concentration and pH of solution (Silva-Weiss et al. 2013). Indeed, too elevated concentration of strong natural compounds might have a negative impact on organoleptic properties of final product. In specific cases, antioxidants might also control the diffusion of gases through films, thus delaying the contact of oxygen and polyphenol oxidase lowering browning (Silva-Weiss et al. 2013). Other hydrocolloids based on cellulose or its derivatives, alginate, corn zein, starch, sodium caseinate, whey or soy protein isolate and gums (arabic, guar) have already been used to effectively reduce oil uptake up to 65% (Dammak et al. 2017; Holikar et al. 2005; Mousa 2018). Al-Asmar et al. (2018) found that fat uptake was reduced due to the increased water retention with pectin (PEC) coating and reduction in the heat transfer coefficient during frying. Jia et al. (2017) showed that guar gum reduced the oil content in French fries by 50.8%. Bouaziz et al. (2016) found that arabic gum with extracts from black pepper, chili, curcumin, coriander and cumin decreased oil content for 45.8% and formation of acrylamide for 20%. Chitosan/whey protein/coconut oil coatings on potato tubers reduced weight loss, respiration, decay percentage, soluble solids, shrinking and wrinkle development (Saha et al. 2014).

Literature data on quality parameters of fresh-cut potato strips during storage as influenced by different edible coatings is rather scarce. Moreover, combination of hydrocolloids with natural antioxidants produced from biowaste for potato storage is not well recorded. Thus, three-stage study was performed with following aims: (1) to evaluate the effect of different edible coatings (carboxymethyl cellulose, chitosan, pectin and gum arabic) on several quality parameters of fresh-cut potatoes during storage period and to select the one(s) having the least influence on the original potato colour, pH and moisture content; (2) to check the stability and properties of potatoes coated with previously selected coatings enriched with olive leaf extract and sodium ascorbate as natural antioxidants during storage period; (3) to test the influence of coatings with antioxidant extracts on the oil uptake and colour changes in deep-fat fried potato strips.

Materials and methods

Materials

Potatoes (*Solanum tuberosum* L. cv Lady Claire) were procured from food industry (Adria Snack Company d.o.o., Zagreb, Croatia). Lady Claire is a Dutch industrial potato cultivar commonly used in chips industry. The potatoes were grown and harvested during 2018 in Slavonia region (Croatia) (45°40′N, 17°1′E). After harvesting, potatoes were treated with an anti-sprouting agent (Gro Stop Basis and Gro Stop Fog, Certis Europe B.V., United Kingdom) and stored in dark at 8 °C with approximately 100% RH. Prior to processing, potatoes were stored at 16 °C/3 days. Commercial grade chitosan (CHI) (France Chitine, France, powder 652, having a molecular mass of 165 kDa, degree of deacetylation of > 85%), pectin (PEC), carboxymethyl cellulose (CMC) and gum arabic (GA) were used as polymers for coatings. Acetic acid (glacial 100%, Merck, Darmstadt, Germany), prepared at 1% w/v solution was used for preparation of chitosan coating, distilled water was used for preparation of CMC, GA and PEC coating solutions, calcium chloride (E509, CAS 10043-52-4) was used

for formation of PEC coatings and sodium ascorbate (SA) (food grade, Sallant, China) was used as synthetic antioxidant. Olive leaves (*Olea europea* L.) were collected in south Croatian region and used for the antioxidant extracts preparation. Sunflower oil (Zvijezda d.o.o., Zagreb, Croatia) was used in frying experiments. Petrol ether (Carlo Erba Reagents S.A.S., France) was used for Soxhlet extractions and Folin-Ciocalteu reagent (Kemika, Zagreb, Croatia) for determination of total phenolic content. No further purification of chemicals has been done and freshly prepared solutions were always used.

Preparation of coating solutions

CHI, PEC, CMC and GA solutions were prepared by dissolving 1 g of polymer powder in 1% aqueous acetic acid solution for CHI and distilled water for other polymers. Solutions were stirred for 2 h at room temperature until the complete solubilisation was obtained. For antioxidant formulations, lyophilised olive leaf extract (OLE) powders or SA were added in coating solutions (1%, w/v) and stirred for 30 min at room temperature to assure complete solubilisation. Freshly prepared solutions were used for the potato strips coating.

Viscosity of freshly prepared coating solutions was measured using RM100Plus Viscosimeter (Lamy Rheology Instruments, France) at a room temperature (25 ± 2 °C) and shear rates at 100 and 1290 s^{-1}. Since the results of measurements on both shear rates followed the same behaviour, only those obtained at 100 s^{-1} will be presented in the Results section.

Preparation of potato samples and frying conditions

Potatoes were hand peeled, washed and cut in regular strips of approximately size of 1 cm × 1 cm × 3 cm with a manual slicer. No chemical washing was applied before or after cutting the potatoes. Strips were then randomly assigned into groups in order to apply the coatings.

Coated and uncoated potato strips were fried in an electrical deep-fat fryer (F21-RCS1, TEFAL, France) in sunflower oil at 180 ± 2 °C for 10 min. In each batch, the samples were put separately and immersed in frying oil. For each batch oil was changed. The oil was drained by shaking the fryer basket and the fried products were allowed to stabilize at room temperature and drawn for further analysis: colour, water content and oil content.

Application of coating solutions

Coating was performed in several experimental series. In the first experimental series, potato strips were randomly distributed into five groups and each coating treatment was applied. Four groups were respectively assigned to four coating treatments: CHI, PEC, CMC, GA and the fifth group was composed of uncoated potatoes dipped only in distilled water and considered as a control group. Dipping in solutions was performed as follows: all potatoes were fresh-cut and then dipped for 0.5, 2 and 10 min. Then, residual solution was allowed to drip off and air dried for 1 h to remove any excess surface moisture. In the case of PEC coating, after dipping in polymer solution potatoes were also dipped in $CaCl_2$ solution (0.1%, w/v) for 30 s in order to polymerise pectin chains. Both coated and uncoated potatoes were vacuum packaged (Dite Hunjek et al. 2020a, b) in separate polyamide/polyethylene (PA/PE) bags (Status, ribbed layer PA 20 µm/PE 70 µm, and flat layer PA 20 µm/PE 70 µm, sealed). Samples were stored at 10 ± 1 °C (Beko, Istanbul, Turkey) for 7 days. At the beginning of storage and after 5 and 7 days physicochemical analysis of the samples were performed.

For antioxidant coatings, dipping was performed as described for other coatings.

Extraction of olive leaf extract

Olive leaves were dried for a week in open space at room temperature and then crushed in small particles with commercial slicer (MCM62020, Bosch, Slovenia). Extraction was performed using 14 mm ultrasound probe (UP200Ht, Hielscher-Ultrasound Technology, Germany) for 10 min at 200 W and amplitude of 100%. Mass/volume ratio was 1:10. Freshly prepared solutions were frozen and lyophilised (Alpha 1–4 LSCplus, Martin Christ Freeze Dryers, Germany) for 48 h. Lyophilised powder was vacuum packed and stored in dark until use.

Determination of total phenols in olive leaf extract

Total phenolic content (TPC) in OLE used for coating (1%, w/v) was determined using Folin-Ciocalteu method reported by Shortle et al. (2014) with slight modifications. Extract (100 µL) was mixed with 200 µL of Folin–Ciocalteu reagent and 2 mL of distilled water. Afterwards, 1 mL of 20% Na_2CO_3 was added. This mixture was incubated at 50 °C /25 min. The absorbance was measured at 765 nm by spectrophotometer (model UV-1600PC; VWR International, Leuven, Belgium). The blank contained 100 µL of the extraction solvent instead of the extract. TPC was expressed as mg of gallic acid equivalent (GAE)/g of prepared extract. All measurements were performed in triplicate.

Experimental setup was done as shown in Supplementary file S1.

Physicochemical analysis

Colour measurements The colour was measured with colorimeter (CHROMA METER CR-5, Konica Minolta, Japan) using CIE Lab colour scale L^* (lightness), a^* (redness) and b^* (yellowness). Triplicate readings were carried out at 25 °C on locations of each strip and the mean value was recorded. The colour of control strips was designated as a reference. The overall difference between two colours, ΔE was calculated from sum of square of difference between each of the L^*, a^*, and b^* values. Whiteness index (WI) was calculated as following:

$$WI = 100 - ((100 - L^*)^2 + a^{*2} + b^{*2})^{1/2} \quad (1)$$

Moisture content and pH The initial weight of potato (0 day) was taken before applying the treatment and then at the end of each storage period (7th day). The difference between the initial and final weight of potato strips was considered as a moisture weight loss at each storage interval.

Homogenous sample was prepared by graining the potatoes with home stick blender (Beko, Type BKK 2262, Turkey) and pH was measured by digital pH meter (Expandable IonAnalyzer EA 940 Millivolt/pH Meter).

Three replicates were made for each treatment.

Moisture and oil content in potato samples Fresh-cut, coated and fried potato strips were homogenized with home stick blender (Beko, Type BKK 2262, Turkey) and obtained pureé was used for dry matter determination by drying in oven at 105 ± 2 °C to constant mass (AOAC 1990). The oil content was measured using the Soxhlet extraction in petrol ether (AOAC 2002).

Percentage of oil reduction capacity (OR) of edible coatings with or without OLE and SA were estimated as percentage of oil content difference between uncoated and coated samples as following:

$$OR(\%) = \frac{(oil\ content\ in\ coated\ sample - oil\ content\ in\ uncoated\ sample)}{oil\ content\ in\ uncoated\ sample} \times 100 \quad (2)$$

Free fatty acid profile The samples were converted to corresponding fatty acid methyl esters (FAMEs) directly by trans-esterification with a methanolic solution of potassium hydroxide (ISO 2000). Approximately 0.1 g of the sample was weighted into plastic test tube and dissolved using 2 mL of isooctane. After that, 200 µL of derivatization reagent (potassium hydroxide solution in methanol, 2 mol L^{-1}) was added and the test tube was vigorously shaken two times for 60 s. The solution was then neutralized by the addition of 1 g of sodium hydrogen sulphate monohydrate and transferred into a 2 mL vial. Supernatant was collected and furtherly tested. The fatty acid composition was determined on a Agilent Technologies 6890 N Network GC System (Santa Clara, SAD) chromatograph using a capillary column DB-23 60 m × 0.25 mm, with a 0.25 µm film thickness (Agilent Technologies, Palo Alto,CA, USA), split/splitless injector, and flame ionization detector. The temperatures of the injector and detector were 250 °C and 280 °C, respectively. Helium was used as a carrier gas at a flow rate of 1.5 mL min^{-1} and the injections were performed in a split ratio 1:30. The temperature program of the column oven was set at 60 °C (1 min) rising to 220 °C at the rate of 7 °C min^{-1}. FAMEs were identified by comparing the retention times of each fatty acid with retention times obtained in the Food Industry FAME standard chromatogram, and the results were calculated through a normalization procedure.

Statistical analysis

For statistical analysis, Statistica ver. 8.0 software (Statsoft Inc., Tulsa, USA) was applied and full factorial randomized experimental design was used. Descriptive statistic was employed for the data basic evaluation, while all continuous variables were analysed by multivariate analysis of variance (MANOVA) and marginal mean values were compared with Tukey's HSD test. In order to examine possible grouping of the samples, Principal Component Analysis (PCA) was conducted. All tests were carried out at the significance level $p \leq 0.05$.

Results

Quality parameters of fresh-cut potatoes coated with edible coatings

The goal of the first experimental series was to select the best potato treatment/coatings that preserves the best

Table 1 Influence of polymer type, dipping time and storage time on pH, moisture (%) and colour parameters (*L**, *a**, *b**, *ΔE*, *WI*) of fresh-cut potato during storage

Source of variation	pH	Moisture (%)	*L**	*a**	*b**	*ΔE*	*WI*
Polymer type	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*
Control	6.25 ± 0.01^{d}	75.14 ± 0.28^{c}	64.11 ± 0.68^{b}	0.70 ± 0.23^{a}	23.31 ± 0.54^{a}	–	57.06 ± 0.49^{d}
CHI	5.73 ± 0.01^{a}	72.52 ± 0.28^{a}	57.62 ± 0.68^{a}	3.52 ± 0.23^{b}	21.54 ± 0.54^{a}	9.89 ± 0.55^{b}	52.07 ± 0.49^{a}
PEC	6.02 ± 0.01^{c}	75.46 ± 0.28^{c}	62.29 ± 0.68^{b}	0.90 ± 0.23^{a}	25.66 ± 0.54^{b}	5.32 ± 0.55^{a}	54.22 ± 0.49^{c}
CMC	6.05 ± 0.01^{c}	75.69 ± 0.28^{c}	62.21 ± 0.68^{b}	0.85 ± 0.23^{a}	26.56 ± 0.54^{b}	6.16 ± 0.55^{a}	53.64 ± 0.49^{ab}
GA	5.94 ± 0.01^{b}	73.87 ± 0.28^{b}	62.64 ± 0.68^{b}	0.95 ± 0.23^{a}	26.17 ± 0.54^{b}	5.55 ± 0.55^{a}	54.23 ± 0.49^{c}
Dipping time (min)	$p < 0.01$*	$p = 0.11$ NS	$p = 0.32$ NS	$p = 0.60$ NS	$p = 0.99$ NS	$p = 0.55$ NS	$p = 0.37$ NS
0.5	5.94 ± 0.01^{a}	74.24 ± 0.22^{a}	61.25 ± 0.53^{a}	1.53 ± 0.18^{a}	24.65 ± 0.42^{a}	5.82 ± 0.42^{a}	53.87 ± 0.38^{a}
2	6.04 ± 0.01^{c}	74.90 ± 0.22^{a}	61.70 ± 0.53^{a}	1.29 ± 0.18^{a}	24.60 ± 0.42^{a}	5.69 ± 0.42^{a}	54.23 ± 0.38^{a}
10	6.01 ± 0.01^{b}	74.47 ± 0.22^{a}	62.37 ± 0.53^{a}	1.34 ± 0.18^{a}	24.69 ± 0.42^{a}	6.31 ± 0.42^{a}	54.63 ± 0.38^{a}
Storage time (day)	$p < 0.01$*	$p < 0.01$*	$p = 0.08$ NS	$p = 0.03$*	$p = 0.32$ NS	$p < 0.01$*	$p < 0.01$*
0	6.23 ± 0.01^{c}	76.11 ± 0.22^{c}	62.74 ± 0.53^{a}	0.99 ± 0.18^{a}	24.16 ± 0.42^{a}	4.70 ± 0.42^{a}	55.46 ± 0.38^{b}
5	5.81 ± 0.01^{a}	74.51 ± 0.22^{b}	61.22 ± 0.53^{a}	1.57 ± 0.18^{b}	25.04 ± 0.42^{a}	7.00 ± 0.42^{b}	53.41 ± 0.38^{a}
7	5.95 ± 0.01^{b}	72.98 ± 0.22^{a}	61.37 ± 0.53^{a}	1.59 ± 0.18^{b}	24.74 ± 0.42^{a}	6.12 ± 0.42^{ab}	53.86 ± 0.38^{a}
Polymer type × storage time (day)	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p = 0.02$*	$p < 0.01$*	$p < 0.01$*
Control × 0	6.65 ± 0.02^{h}	77.88 ± 0.49^{f}	64.90 ± 1.17^{c}	0.50 ± 0.40^{a}	22.81 ± 0.93^{abcd}	–	58.13 ± 0.85^{ef}
Control × 5	6.26 ± 0.02^{fg}	74.44 ± 0.49^{bcd}	64.47 ± 1.17^{c}	0.81 ± 0.40^{a}	24.95 ± 0.93^{bcd}	5.38 ± 0.95^{bc}	56.27 ± 0.85^{cdef}
Control × 7	5.83 ± 0.02^{cd}	73.11 ± 0.49^{b}	62.95 ± 1.17^{c}	0.80 ± 0.40^{a}	22.16 ± 0.93^{abc}	2.50 ± 0.95^{a}	56.78 ± 0.85^{def}
CHI × 0	5.87 ± 0.02^{d}	75.13 ± 0.49^{bcde}	64.35 ± 1.17^{c}	1.57 ± 0.40^{a}	19.85 ± 0.93^{a}	5.29 ± 0.95^{bc}	59.07 ± 0.85^{f}
CHI × 5	5.55 ± 0.02^{a}	72.87 ± 0.49^{b}	51.51 ± 1.17^{a}	4.45 ± 0.40^{b}	20.61 ± 0.93^{ab}	14.46 ± 0.95^{d}	46.85 ± 0.85^{a}
CHI × 7	5.77 ± 0.02^{bc}	69.56 ± 0.49^{a}	57.00 ± 1.17^{ab}	4.53 ± 0.40^{b}	24.15 ± 0.93^{abcd}	9.94 ± 0.95^{cd}	50.28 ± 0.85^{ab}
PEC × 0	6.02 ± 0.02^{e}	77.45 ± 0.49^{ef}	61.00 ± 1.17^{bc}	0.69 ± 0.40^{a}	25.84 ± 0.93^{cd}	6.47 ± 0.95^{bc}	52.99 ± 0.85^{bcd}
PEC × 5	5.71 ± 0.02^{b}	74.06 ± 0.49^{bcd}	63.86 ± 1.17^{c}	0.72 ± 0.40^{a}	26.40 ± 0.93^{cd}	4.64 ± 0.95^{ab}	55.11 ± 0.85^{cdef}
PEC × 7	6.31 ± 0.02^{fg}	74.88 ± 0.49^{bcd}	62.00 ± 1.17^{bc}	1.29 ± 0.40^{a}	24.73 ± 0.93^{bcd}	4.84 ± 0.95^{ab}	54.55 ± 0.85^{cde}
CMC × 0	6.24 ± 0.02^{f}	76.55 ± 0.49^{def}	59.95 ± 1.17^{bc}	1.18 ± 0.40^{a}	26.03 ± 0.93^{cd}	6.80 ± 0.95^{bc}	52.12 ± 0.85^{bc}
CMC × 5	5.83 ± 0.02^{cd}	75.97 ± 0.49^{cdef}	63.39 ± 1.17^{c}	0.85 ± 0.40^{a}	26.29 ± 0.93^{cd}	5.21 ± 0.95^{b}	54.81 ± 0.85^{cde}
CMC × 7	6.08 ± 0.02^{e}	74.55 ± 0.49^{bcd}	63.30 ± 1.17^{c}	0.51 ± 0.40^{a}	27.37 ± 0.93^{d}	6.47 ± 0.95^{bc}	54.00 ± 0.85^{bcde}
GA × 0	6.34 ± 0.02^{g}	73.54 ± 0.49^{bc}	63.52 ± 1.17^{c}	1.01 ± 0.40^{a}	26.25 ± 0.93^{cd}	4.50 ± 0.95^{ab}	54.97 ± 0.85^{cdef}
GA × 5	5.71 ± 0.02^{b}	75.23 ± 0.49^{bcde}	62.84 ± 1.17^{c}	1.03 ± 0.40^{a}	26.97 ± 0.93^{d}	5.29 ± 0.95^{bc}	54.02 ± 0.85^{bcde}
GA × 7	5.78 ± 0.02^{bcd}	72.83 ± 0.49^{b}	61.58 ± 1.17^{bc}	0.80 ± 0.40^{a}	25.29 ± 0.93^{cd}	6.85 ± 0.95^{bc}	53.69 ± 0.85^{bcd}
Grand mean	6.00	74.54	61.77	1.38	24.65	5.94	54.24

CHI chitosan, *PEC* pectin, *CMC* carboxymethyl cellulose, *GA* gum arabic. *$p \leq 0.05$, *NS* not significant (p p 0.05). Results are expressed as mean ± SE. Values with different letters within column ($^{a–f}$) are statistically different at $p \leq 0.05$

original quality of fresh-cut potatoes (pH, moisture content and colour in vacuum packaged raw samples), considering polymer type and dipping time.

Obtained results are given in Table 1. Control sample had pH around 6.65, which decreased up to 5.83 in packaged samples during 7 days of storage. This result is similar (pH 6.6) to the data published by Rocha et al. (2003) and 5.63 by Saha et al. (2014). In coated potato slices, significant decrease was the highest for CHI, followed by PEC, CMC and GA. This behaviour is probably result of the pH of CHI solution as it is prepared in weak acidic conditions (1% acetic acid, v/v). Results also indicate that most of the samples became more acidic during storage, probably due to the respiration and CO_2 concentration increase within the package and its reaction with moisture present in potato (Soliva-Fortuny et al. 2002). Dipping time seemed to have also influence on those behaviours. With dipping time increase, pH significantly increases (Table 1).

Moisture content in control samples slightly decreased with storage time (Table 1). Initial moisture content after coating process was lower in CHI and GA samples, while no differences was observed for PEC and CMC. During storage, the highest difference was measured for CHI, followed by GA, while no significant changes, in comparison to control group, could be seen for PEC and CMC. Immersion time did not influence the moisture content. According to Kizito et al. (2017) differences could be attributed to the variations in coating mechanical strength and pick up which depends on coating viscosity. Indeed, results on coating viscosity in this study varied depending on the polymer type and the addition of extracts. GA coatings had the lowest viscosity values (3, 2.3 and 2.7 mPa s for GA, GA/SA and GA/OLE, respectively), followed by PEC (12.3, 23.7 and 21.0 mPa s for PEC, PEC/SA and PEC/OLE, respectively) and CMC (12.7, 8.7, and 11.7 mPa s for CMC, CMC/SA and CMC/OLE, respectively). Highest viscosity had all types of CS coatings (24, 23.4 and 45.0 mPa s for CS, CS/SA and CS/OLE, respectively). Even though results on coating viscosity could not be correlated with water content in freshly prepared samples (no significant changes were observed), results on moisture content and fat reduction in fried samples could be correlated as explained later in 3.3.

Pictures of all samples during storage are given in Table 2. During storage, only CHI coatings showed significant changes in L^* and a^* in comparison with control (Table 1). The L^* value is an important parameter that affects the attractiveness of cut samples. Lower values reflect pale and "not-fresh" appearance. Increasing value indicates reddish taint and has strong correlation with browning (Du et al. 2009). In CHI samples, a^* significantly increased already after 5-days storage. Surprisingly, Waimaleongora-Ek et al. (2008) found that CHI films well preserved colour and moisture content in sweet potato during 17 days at 4 °C. Differences might be in the potato samples. Recently, Wu (2019) reported that potatoes treatment with cactus based coating (1% solution, w/v) effectively suppressed browning, respiration rate and inhibited weight loss during storage at 5 °C. Differences in observations in present study might also be due to the fact that samples were packed in vacuum, meaning without oxygen, so minimal changes in tested parameters already in control group were logic. Immersion time did not have any significant effect on colour parameters. CMC, PEC and GA were shown as effective in prevention of potato browning. Similarly, Shon and Choi (2011) showed that soy protein coatings on potatoes effectively protected slices from oxygen and they reduced browning as well. ΔE was the highest for CHI (14.46 after 5-days storage) and whiteness (WI) of these samples also significantly decreased indicating browning occurrence (Table 1).

Results given above and Principal Component Analysis (PCA), (Fig. 1a) indicated that CHI coating can be classified as not appropriate for the preservation of original quality of fresh-cut potatoes stored at 10 ± 1 °C during 7 days, as significant changes in pH, moisture content and colour parameters occurred. Therefore, in the second experimental series, only CMC, PEC and GA were used.

Quality of fresh-cut potatoes coated with enriched edible coatings

Total amount of phenols in 1% solution of OLE was 895.71 ± 90.91 mg/L (data not shown). Statistical analysis of the results of pH, moisture and colour parameters of potato strips coated with CMC, PEC and GA solutions with either OLE or SA, vacuum packaged and stored at 10 ± 1 °C during 7 days are given in Table 3.

pH of all tested samples decreased with storage time. All coated samples had lower pH with no significant differences between polymer types. Both antioxidants had significant impact on pH. All coatings with OLE and CMC/SA had lower pH compared to control sample. No significant changes were seen for moisture content in all coated samples compared to control (Table 3). Regarding storage time, trend was the same as for the first experimental series.

Polymer type had significant impact only on L^* and a^* in PEC (Table 3). For this reason, all PEC based samples were discarded for frying experiments. Darker taint in samples with extract (lowest L^*) was due to the original greenish taint of OLE extract (Table 2).

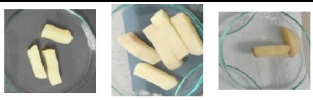
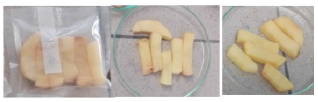
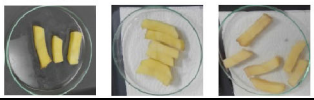
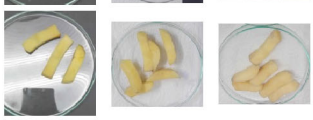
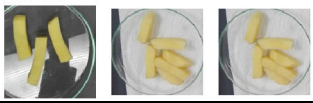
In a similar study, authors showed that lower concentrations of natural antioxidant purslane plant (*Portulaca oleracea*) (0.05%) extract inhibited the browning of potato slices during 8 days storage in air packaged PE bags at 4 °C (Liu et al. 2019). Efficiency of natural plant-based antioxidant extracts depend on the applied concentration. Generally, addition of SA did not statistically changed colour of samples compared to control, while addition of OLE decreased WI. Similarly, Ojeda et al. (2014) found that it was necessary to add ascorbic acid to cassava coating, as pure polymer was not effective in browning prevention. Among all samples, overall colour change ΔE and WI were the most important for PEC/OLE (Table 3).

As shown in Principal Component Analysis (Fig. 1b), grouping of coated samples enriched with OLE confirmed above discussed results.

Fat reduction, moisture content, colour and free fatty acid profile in fresh-cut potatoes coated with enriched edible coatings

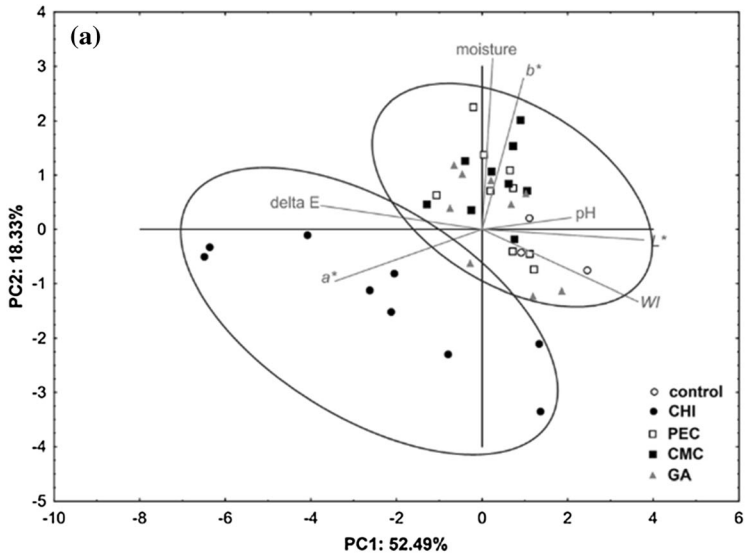
Fat reduction (%) and moisture content (%) in fried fresh-cut potatoes are given in Table 4. Generally, significant

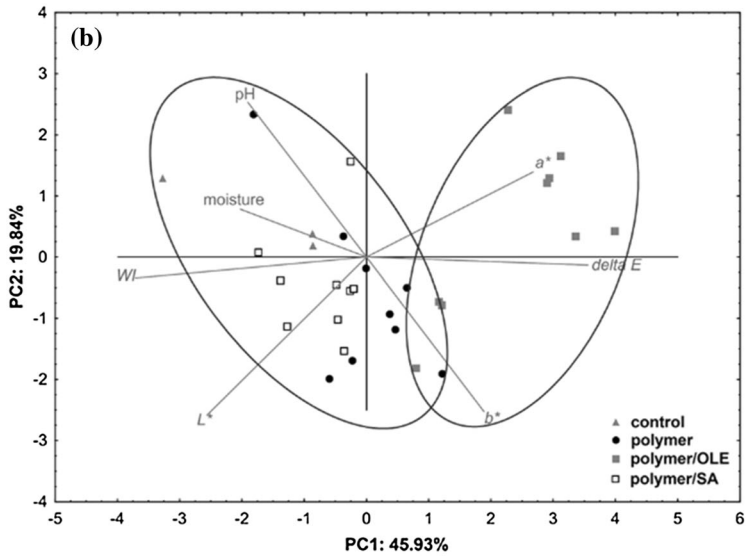
Table 2 Pictures of potato samples (uncoated and coated) during 7 days storage at 10 ± 1 °C

Sample	DT (min)	Storage time (days) 0	5	7	Sample	DT time	Storage time (days) 0	5	7
C	10								
CHI	0,5								
	2								
	10								
PEC	0,5				**PEC/ OLE**	10			
	2				**PEC/ SA**	10			
	10								
CMC	0,5				**CMC/ OLE**	10			
	2				**CMC/ SA**	10			
	10								
GA	0,5				**GA/ OLE**	10			
	2				**GA/ SA**	10			
	10								

DT dipping time, *C* control, *CHI* chitosan, *PEC* pectin, *CMC* carboxymethyl cellulose, *GA* gum arabic, *OLE* olive leaf extract, *SA* sodium ascorbate

reduction in fat content was noticed in all coated samples compared to uncoated ones. With the addition of OLE, fat content in fried potatoes was reduced up to 45% for CMC. Similarly, Garmakhany, Mirzaei, Nejad, & Maghsudlo (2008) reported that potato chips coated with 1% CMC resulted in 57% fat reduction. Coating formulations on





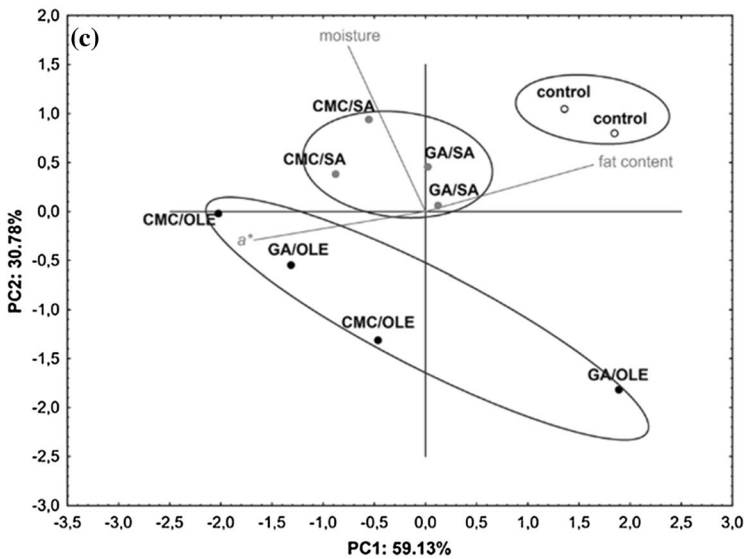


Fig. 1 Distribution of samples in two dimensional coordinate system defined by the first two principal components (PC1 and PC2) of **a** fresh-cut potato samples regarding polymer type; **b** fresh-cut potato samples coated with polymer containing antioxidant; c) fried potato samples coated with polymer containing antioxidant. Below graphs: **a** PC1—axis explaining 52.49% variability among the samples included in the test, PC2—the second axes explaining 18.33% variability. **b** PC1—axis explaining 45.93% variability among the samples included in the test, PC2—the second axes explaining 19.84% variability. **c** PC1—axis explaining 59.13% variability among the samples included in the test; PC2—the second axes explaining 30.78% variability. *CHI* chitosan, *PEC* pectin, *CMC* carboxymethyl cellulose, *GA* gum arabic, *OLE* olive leaf extract, *SA* sodium ascorbate

Table 3 Influence of antioxidant, polymer type, dipping and storage time on pH, moisture (%) and color parameters (*L**, *a**, *b**, *ΔE*, *WI*) of raw fresh-cut potato

Source of variation	pH	Moisture (%)	*L**	*a**	*b**	*ΔE*	*WI*
Antioxidant type	$p < 0.01$*	$p = 0.09$ NS	$p < 0.01$*	$p < 0.01$*	$p = 0.27$ NS	$p < 0.01$*	$p < 0.01$*
0	6.07 ± 0.01^{c}	74.98 ± 0.43^{a}	64.04 ± 0.58^{b}	0.65 ± 0.08^{b}	26.03 ± 0.46^{a}	5.52 ± 0.42^{a}	54.03 ± 0.33^{b}
OLE	5.96 ± 0.01^{a}	74.72 ± 0.43^{a}	59.61 ± 0.58^{a}	1.71 ± 0.08^{c}	26.40 ± 0.46^{a}	7.66 ± 0.42^{b}	51.57 ± 0.33^{a}
SA	6.01 ± 0.01^{b}	76.02 ± 0.43^{a}	63.08 ± 0.58^{b}	0.33 ± 0.08^{a}	25.34 ± 0.46^{a}	4.67 ± 0.42^{a}	55.07 ± 0.33^{b}
Polymer type	$p < 0.01$*	$p = 0.52$ NS	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*	$p < 0.01$*
Control	6.26 ± 0.01^{b}	75.14 ± 0.49^{a}	63.79 ± 0.68^{b}	0.72 ± 0.09^{a}	23.21 ± 0.53^{a}	–	56.79 ± 0.39^{b}
PEC	5.94 ± 0.01^{a}	75.33 ± 0.49^{a}	60.04 ± 0.68^{a}	1.21 ± 0.09^{b}	26.46 ± 0.53^{b}	6.44 ± 0.48^{b}	52.81 ± 0.39^{a}
CMC	5.93 ± 0.01^{a}	74.73 ± 0.49^{a}	62.83 ± 0.68^{b}	0.80 ± 0.09^{a}	27.22 ± 0.53^{b}	6.80 ± 0.48^{b}	52.57 ± 0.39^{a}
GA	5.93 ± 0.01^{a}	75.76 ± 0.49^{a}	62.32 ± 0.68^{ab}	0.87 ± 0.09^{ab}	26.79 ± 0.53^{b}	7.18 ± 0.48^{b}	52.07 ± 0.39^{a}
Storage time (day)	$p < 0.01$*	$p = 0.01$*	$p = 0.30$ NS	$p < 0.01$*	$p = 0.39$ NS	$p = 0.83$ NS	$p = 0.18$ NS
0	6.34 ± 0.01^{c}	76.41 ± 0.43^{b}	62.03 ± 0.58^{a}	1.09 ± 0.08^{b}	25.58 ± 0.46^{a}	5.83 ± 0.42^{a}	53.10 ± 0.33^{a}
5	5.88 ± 0.01^{b}	74.83 ± 0.43^{a}	62.97 ± 0.58^{a}	0.68 ± 0.08^{a}	26.44 ± 0.46^{a}	6.16 ± 0.42^{a}	54.00 ± 0.33^{a}
7	5.82 ± 0.01^{a}	74.48 ± 0.43^{a}	61.73 ± 0.58^{a}	0.93 ± 0.08^{ab}	25.74 ± 0.46^{a}	5.87 ± 0.42^{a}	53.57 ± 0.33^{a}
Polymer type × antioxidant type	$p < 0.01$*	$p < 0.01$*	$p = 0.03$*	$p < 0.01$*	$p = 0.88$ NS	$p = 0.01$*	$p < 0.01$*
Control × 0	6.26 ± 0.01^{f}	75.14 ± 0.85^{abc}	63.79 ± 1.17^{c}	0.72 ± 0.16^{ab}	23.21 ± 0.93^{a}	–	56.79 ± 0.67^{e}
PEC × 0	6.09 ± 0.01^{e}	77.20 ± 0.85^{bc}	61.94 ± 1.17^{bc}	1.00 ± 0.16^{bc}	27.11 ± 0.93^{ab}	3.90 ± 0.83^{ab}	55.78 ± 0.67^{e}
CMC × 0	5.94 ± 0.01^{bcd}	74.05 ± 0.85^{abc}	65.42 ± 1.17^{c}	0.55 ± 0.16^{ab}	27.46 ± 0.93^{ab}	6.90 ± 0.83^{abcd}	52.08 ± 0.67^{bcd}
GA × 0	6.00 ± 0.01^{d}	73.52 ± 0.85^{ab}	65.00 ± 1.17^{c}	0.33 ± 0.16^{ab}	26.33 ± 0.93^{ab}	7.89 ± 0.83^{bcd}	51.47 ± 0.67^{abc}
Control × OLE	6.26 ± 0.01^{f}	75.14 ± 0.85^{abc}	63.79 ± 1.17^{c}	0.72 ± 0.16^{ab}	23.21 ± 0.93^{a}	3.38 ± 0.83^{a}	56.79 ± 0.67^{e}
PEC × OLE	5.85 ± 0.01^{a}	72.04 ± 0.85^{a}	56.09 ± 1.17^{a}	2.42 ± 0.16^{d}	27.09 ± 0.93^{ab}	10.05 ± 0.83^{d}	48.32 ± 0.67^{a}
CMC × OLE	5.88 ± 0.01^{abc}	76.03 ± 0.85^{abc}	60.83 ± 1.17^{abc}	1.69 ± 0.16^{cd}	27.84 ± 0.93^{b}	8.46 ± 0.83^{cd}	51.73 ± 0.67^{bc}
GA × OLE	5.85 ± 0.01^{a}	75.68 ± 0.85^{abc}	57.75 ± 1.17^{ab}	2.03 ± 0.16^{d}	27.44 ± 0.93^{ab}	8.76 ± 0.83^{cd}	49.47 ± 0.67^{ab}
Control × SA	6.26 ± 0.01^{f}	75.14 ± 0.85^{abc}	63.79 ± 1.17^{c}	0.72 ± 0.16^{ab}	23.21 ± 0.93^{a}	3.38 ± 0.83^{a}	56.79 ± 0.67^{e}
PEC × SA	5.87 ± 0.01^{ab}	76.75 ± 0.85^{bc}	62.09 ± 1.17^{bc}	0.20 ± 0.16^{ab}	25.18 ± 0.93^{ab}	5.37 ± 0.83^{abc}	54.34 ± 0.67^{cde}
CMC × SA	5.98 ± 0.01^{d}	74.11 ± 0.85^{abc}	62.25 ± 1.17^{bc}	0.15 ± 0.16^{a}	26.36 ± 0.93^{ab}	5.04 ± 0.83^{abc}	53.89 ± 0.67^{cde}
GA × SA	5.95 ± 0.01^{cd}	78.09 ± 0.85^{c}	64.21 ± 1.17^{c}	0.25 ± 0.16^{ab}	26.60 ± 0.93^{ab}	4.89 ± 0.83^{abc}	55.27 ± 0.67^{de}
Grand mean	6.02	75.24	62.24	0.90	25.92	5.95	53.56

OLE olive leaf extract, *SA* sodium ascorbate, *PEC* pectin, *CMC* carboxymethyl cellulose, *GA* gum arabic. *$p \leq 0.05$, *NS* not significant ($p > 0.05$). Results are expressed as mean ± SE. Values with different letters within column ($^{a–f}$) are statistically different at $p \leq 0.05$

Table 4 Influence of polymer type and storage time on moisture (%), fat content (%) and colour parameters (*L**, *a**, *b**, *ΔE, WI*) of fried potato samples

Source of variation	Moisture (%)	Fat content (%)	*L**	*a**	*b**	*ΔE*	*WI*
Polymer type	$p < 0.01$*	$p < 0.01$*	$p = 0.61$ ns	$p < 0.01$*	$p = 0.08$ ns	$p = 0.14$ ns	$p = 0.41$ ns
Control	56.55 ± 3.02^{b}	9.07 ± 0.33^{b}	67.16 ± 2.43^{a}	-1.76 ± 0.19^{a}	29.62 ± 1.28^{a}	–	55.51 ± 1.41^{a}
CMC/OLE	49.93 ± 3.02^{ab}	6.40 ± 0.33^{a}	71.56 ± 2.43^{a}	0.18 ± 0.19^{c}	34.87 ± 1.28^{a}	7.56 ± 1.41^{a}	54.80 ± 1.41^{a}
CMC/SA	61.64 ± 3.02^{b}	7.05 ± 0.33^{a}	71.14 ± 2.43^{a}	-0.47 ± 0.19^{c}	33.94 ± 1.28^{a}	6.21 ± 1.41^{a}	55.29 ± 1.41^{a}
GA/OLE	39.72 ± 3.02^{a}	7.49 ± 0.33^{a}	72.31 ± 2.43^{a}	-0.60 ± 0.19^{bc}	30.82 ± 1.28^{a}	5.29 ± 1.41^{a}	58.53 ± 1.41^{a}
GA/SA	55.68 ± 3.02^{b}	6.91 ± 0.33^{a}	71.49 ± 2.43^{a}	-1.43 ± 0.19^{ab}	32.43 ± 1.28^{a}	7.62 ± 1.41^{a}	56.55 ± 1.41^{a}
Storage time (day)	$p = 0.02$*	$p = 0.03$*	p= 0.76 ns	$p = 0.01$*	p= 0.68 ns	p= 0.09 ns	p= 0.59 ns
0	49.04 ± 1.91^{a}	7.77 ± 0.21^{b}	70.39 ± 1.54^{a}	-1.10 ± 0.12^{a}	32.58 ± 0.81^{a}	4.67 ± 0.89^{a}	55.78 ± 0.89^{a}
7	56.37 ± 1.91^{b}	7.00 ± 0.21^{a}	71.07 ± 1.54^{a}	-0.53 ± 0.12^{b}	32.09 ± 0.81^{a}	7.02 ± 0.89^{a}	56.49 ± 0.89^{a}
Polymer type × storage time (day)	$p = 0.03$*	$p = 0.36$ ns	$p = 0.97$ ns	$p = 0.01$*	$p = 0.02$*	$p = 0.42$ ns	$p = 0.13$ ns
Control × 0	54.66 ± 4.27^{b}	9.07 ± 0.47^{a}	67.46 ± 3.44^{a}	-2.02 ± 0.27^{a}	30.28 ± 1.81^{ab}	–	55.26 ± 1.99^{a}
Control × 7	58.44 ± 4.27^{b}	9.06 ± 0.47^{a}	66.87 ± 3.44^{a}	-1.51 ± 0.27^{ab}	28.97 ± 1.81^{ab}	5.11 ± 1.99^{a}	55.77 ± 1.99^{a}
CMC/OLE × 0	41.20 ± 4.27^{ab}	6.54 ± 0.47^{a}	70.59 ± 3.44^{a}	-0.42 ± 0.27^{bcd}	31.51 ± 1.81^{ab}	5.14 ± 1.99^{a}	56.68 ± 1.99^{a}
CMC/OLE × 7	58.67 ± 4.27^{b}	6.25 ± 0.47^{a}	72.54 ± 3.44^{a}	0.78 ± 0.27^{d}	38.24 ± 1.81^{b}	9.97 ± 1.99^{a}	52.91 ± 1.99^{a}
CMC/SA × 0	63.75 ± 4.27^{b}	7.40 ± 0.47^{a}	70.38 ± 3.44^{a}	-0.49 ± 0.27^{bcd}	32.63 ± 1.81^{ab}	4.57 ± 1.99^{a}	55.81 ± 1.99^{a}
CMC/SA × 7	59.54 ± 4.27^{b}	6.70 ± 0.47^{a}	71.89 ± 3.44^{a}	-0.46 ± 0.27^{bcd}	35.26 ± 1.81^{ab}	7.86 ± 1.99^{a}	54.77 ± 1.99^{a}
GA/OLE × 0	28.24 ± 4.27^{a}	8.45 ± 0.47^{a}	73.15 ± 3.44^{a}	-1.54 ± 0.27^{ab}	31.61 ± 1.81^{ab}	5.88 ± 1.99^{a}	58.49 ± 1.99^{a}
GA/OLE × 7	51.21 ± 4.27^{ab}	6.53 ± 0.47^{a}	71.47 ± 3.44^{a}	0.34 ± 0.27^{cd}	30.04 ± 1.81^{ab}	4.71 ± 1.99^{a}	58.56 ± 1.99^{a}
GA/SA × 0	57.36 ± 4.27^{b}	7.38 ± 0.47^{a}	70.38 ± 3.44^{a}	-1.04 ± 0.27^{abc}	36.90 ± 1.81^{ab}	7.76 ± 1.99^{a}	52.66 ± 1.99^{a}
GA/SA × 7	54.00 ± 4.27^{b}	6.44 ± 0.47^{a}	72.61 ± 3.44^{a}	-1.82 ± 0.27^{ab}	27.97 ± 1.81^{a}	7.48 ± 1.99^{a}	60.45 ± 1.99^{a}
Grand mean	52.70	7.38	70.73	−0.82	32.34	5.58	56.14

CMC/OLE carboxymethyl cellulose/olive leaf extract, *CMC/SA* carboxymethyl cellulose/sodium ascorbate, *GA/OLE* gum arabic/olive leaf extract, *GA/SA* gum arabic/sodium ascorbate

*$p \leq 0.05$, ns = not significant (p 0.05). Results are expressed as mean ± SE. Values with different letters within column ($^{a–d}$) are statistically different at $p \leq 0.05$

potato surface avoid pores and cracks formation in the fried products. Data that can be found in scientific literature about effectiveness of different coatings varies depending on the coating type and treatment. Oil uptake also significantly depends on the shape and size of the sample, as it is strongly influenced by the surface of exchange heat and water (Lumanlan et al. 2019). In addition, by increasing coating viscosity (CMC > GA), fried samples retained more moisture and had less fat (Table 4). Frying after 7 days of storage had positive impact on lower fat content in fried samples (Table 4). This is an important information indicating the activity of coatings even after 7-day storage. Valuable explanations about fat reduction mechanisms are given in scientific literature (Kurek et al. 2017; Liberty et al. 2019). For example, Yu et al. (2016) found that coating with guar gum and glycerol could effectively hinder the oil absorption of fried potato chips and have no negative effects on its breaking force.

Free fatty acid (FFA) profile in all tested samples is given in Table 5. FFA profile in raw potatoes, is similar to data already reported in the scientific literature, and is the highest with linoleic acid (26.15%) content (Popović-Djordjević et al. 2018). In fried potatoes following fatty acids, which are not naturally present in raw potato, occurred: C14:0, C16:1, C20:0, C20:1, C22:0, C24:0, and C18:2t (Table 5). Their appearance is attributed to the oil absorbed from sunflower oil used for frying. Presence of *trans* linoleic acid (C18:2t) might negatively influence sensorial evaluation of fried potatoes due to the degeneration at higher temperature via hydrogenation. In fried samples there was also an increase of C16:0, C18:0, C18:2c, and decrease of C17:0, C18:3n3 and C22:2. Following fatty acids: C18:2 and C18:3n6 were not detected probably due to their degradation. There is no significant difference between coatings and antioxidants used compared to control sample. Similar observations were already reported by Kizito et al. (2017), who showed that CMC

Table 5 Free fatty acid profile and their content (%) in raw potato, sunflower oil used for frying and fried samples without or with edible coatings (GA, CMC) with antioxidants (SA, OLE)

Fatty acid	Free fatty acid content (%)						
	Raw potato	Oil	Control	GA/OLE	CMC/OLE	GA/SA	CMC/SA
C8:0	11,2^{b}	ND	ND	ND	ND	0,03^{a}	ND
C14:0	ND	0,07^{a}	0,08^{a}	0,08^{a}	0,08^{a}	0,08^{a}	0,08^{a}
C16:0	5,6^{a}	6,17^{b}	6,55^{c}	6,59^{c}	6,58^{c}	6,73^{d}	6,71^{d}
C16:1	ND	0,1^{a}	0,11^{a}	0,1^{a}	0,11^{a}	0,12^{a}	0,11^{a}
C17:0	18,99^{b}	0,04^{a}	0,05^{a}	0,08^{a}	0,05^{a}	ND	0,05^{a}
C18:0	2,67^{a}	3,22^{b}	3,34^{c}	3,36^{c}	3,40^{c}	3,35^{c}	3,41^{c}
C18:1	9,08	ND	ND	ND	ND	ND	ND
C18:1c	ND	35,41	ND	ND	ND	ND	ND
C18:2t	ND	ND	33,65^{a}	33,7^{a}	33,90^{a}	33,66^{a}	33,87^{a}
C18:2c	8,23^{a}	53,48^{b}	54,60^{b}	54,28^{b}	54,29^{b}	54,20^{b}	54,08^{b}
C18:3n6	12,18	ND	ND	ND	ND	ND	ND
C18:3n3	26,15^{b}	0,08^{a}	0,15^{a}	0,16^{a}	0,18^{a}	0,19^{a}	0,20^{a}
C20:0	ND	0,24^{a}	0,24^{a}	0,24^{a}	0,25^{a}	0,24^{a}	0,25^{a}
C20:1	ND	0,19^{a}	0,18^{a}	0,28^{b}	0,19^{a}	0,19^{a}	0,19^{a}
C22:0	ND	0,73^{a}	0,70^{a}	0,71^{a}	0,74^{a}	0,68^{a}	0,70^{a}
C22:2	5,86^{c}	ND	0,12^{a}	0,10^{a}	ND	0,30^{b}	0,11^{a}
C24:0	ND	0,25^{a}	0,23^{a}	0,23^{a}	0,25^{a}	0,22^{a}	0,23^{a}

ND not detected, *CMC* carboxymethyl cellulose, *GA* gum arabic, *OLE* olive leaf extract, *SA* sodium ascorbate

Values with different letters within a line ($^{a–d}$) indicate significant differences among samples ($p \leq 0.05$)

coating did not influence the content of free fatty acids, peroxide number and fatty oxidation in fried potatoes.

During frying, oil replaces water in potato tissue. Moisture content in fried samples decreased from 56.55% (control) to 49.93% in CMC/OLE and 39.72% in GA/OLE coatings. Slightly higher values were obtained in coatings with SA, however this change was not statistically significant in comparison with other coatings with OLE. Statistical analysis showed that all coated samples were significantly different from control (Table 4). Considering the results obtained for both water content and fat reduction, it is clear that fat reduction mechanism is a result of combination of changes in water content and modulation of heat transfer from the surrounding oil to the potato strips. Similar values were found in the work of Al-Asmar et al. (2018) who showed that pectin based coatings did not significantly changed the water content in fried potatoes.

There were no significant differences in L^*, b^*, *WI* and ΔE values of fried samples neither for coating type nor for sodium ascorbate (Table 4). Fried coated samples had higher a^* than control indicating brownish taint of fried samples. ΔE was calculated with regard to uncoated fried sample on the day of frying. Statistically, there were no significant differences among polymers and antioxidants used, which was similar to results given by Kizito et al. (2017) (Table 4).

Principal Component Analysis (Fig. 1c) showed great separation of three types of fried samples: (1) control set of samples that is separated due to the higher fat content; (2) polymer/SA set grouped in the middle and (3) polymer/OLE set grouped apart and distancing oppositely to fat content and according to similarity in a^* value.

It follows that both tested polymers (CMC and GA) and both extracts (SA and OLE) can be used for frying potato strips in order to reduce fat content of final sample with no significant overall impact on visual and/or sensorial acceptability of samples.

Conclusion

Carboxymethyl cellulose and gum arabic in combination with natural antioxidants (olive leaf extract (OLE) and sodium ascorbate (SA)) successfully decreased the fat content up to 45% in comparison to uncoated samples. In addition, these coatings did not significantly changed colour, pH and moisture content of fresh-cut potatoes. Similar behaviour was observed for samples tested and fried the day of coating process, as well as after 7 days storage at 10 ± 1 °C. Among four tested polymers (CMC, PEC, GA and CHI), only chitosan was shown as not appropriate

coating material causing unacceptable and significant colour and pH changes.

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