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Dite Hunjek, Draženka

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Faculty of Food Technology and Biotechnology

Draženka Dite Hunjek

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DOCTORAL THESIS

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DOCTORAL THESIS

Supervisor:
Branka Levaj, Ph.D., Full Professor

Zagreb, 2021

Sveučilište u Zagrebu

Prehrambeno-biotehnološki fakultet

Draženka Dite Hunjek

UTJECAJ SIROVINE I UVJETA PROIZVODNJE NA TRAJNOST I KAKVOĆU MINIMALNO PROCESIRANOGA KRUMPIRA (*Solanum tuberosum*)

DOKTORSKI RAD

Mentor:
prof. dr.sc.Branka Levaj

Zagreb, 2021

Draženka Dite Hunjek

Influence of raw material and processing conditions on shelf-life and quality of minimally processed potato (*Solanum tuberosum*)

Supervisor:

Branka Levaj, Ph.D., Full Professor **(**the University of Zagreb, Faculty of Food Technology and Biotechnology, Laboratory for Chemistry and Technology of Fruits and Vegetables)

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INFLUENCE OF RAW MATERIAL AND PROCESSING CONDITIONS ON SHELF-LIFE AND QUALITY OF MINIMALLY PROCESSED POTATO (*Solanum tuberosum*)

Draženka Dite Hunjek

Thesis was performed at the Laboratory for Chemistry and Technology of Fruits and Vegetables, Faculty of Food Technology and Biotechnology, University of Zagreb
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Short abstract:

The aim of this study was to examine the impact of raw potato (cv. Birgit and Lady Claire during aging), processing conditions (anti-browning agent, type of packaging), and storage conditions on the quality and safety as well as sensory properties of minimally processed potatoes (MPP) (raw and subsequently thermaly treated). Regardless of tubers age, cv. Birgit, treatment with sodium ascorbate solution (2%), vacuum packaged and storage for 8 days at 3 and 10 °C showed the best results in terms of preserving the quality and safety as well as sensory properties of MPP (for both raw and thermaly treated samples). The acrylamide and polycyclic aromatic hydrocarbons (PAHs) content in the fried samples were also analyzed and they were under the limits according to the official regulation independently of investigated sources of variation.

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UTJECAJ SIROVINE I UVJETA PROIZVODNJE NA TRAJNOST I KAKVOĆU MINIMALNO PROCESIRANOGA KRUMPIRA (*Solanum tuberosum*)

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Cilj ovoga rada bio je ispitati utjecaj sirovog krumpira (sorte Birgit i Lady Claire) tijekom starenja, uvjeta proizvodnje (sredstvo protiv posmeđivanja, uvjeti pakiranja) i uvjeta skladištenja na kvalitetu i sigurnost kao i senzorska svojstva minimalno procesiranoga krumpira (MPK) (sirovog i naknadno termički tretiranog). Sorta Birgit tretirana otopinom natrijevog askorbata (2%), pakirana u vakuumu i skladištena tijekom 8 dana pri 3 i 10 °C, bez obzira na starost gomolja, dala je najbolje rezultate u pogledu očuvanja kvalitete i zdravstvene ispravnosti te senzorskih svojstava MPK (sirovog i naknadno termički obrađenog). Udio akrilamida i policikličih aromatskih ugljikovodika (PAH-ova) u prženim uzorcima također je bio analiziran, a njihova vrijednost je bila ispod maksimalno dozvoljenih granica propisanih zakonskim odredbama neovisno o istraživanim izvorima varijacija.

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The dissertation topic was accepted at the 5th regular session of the Faculty Council of the Faculty of Food Technology and Biotechnology, University of Zagreb in the academic year 2018/2019 held on February 28, 2019.

ABSTRACT

The aim of this study was to examine the impact of raw potato (cv. Birgit and Lady Claire) during aging, processing conditions applied (anti - browning agent, type of packaging materials and methods), and storage conditions on the quality and safety as well as sensory properties of minimally processed potatoes (MPP) (raw and thermally treated). The research described in the doctoral thesis consists of three parts. The first and second part of the research include a study of the influence of cultivar, tubers age, anti-browning agents, packaging conditions , temperature and storage time of MPP on the quality and sensory properties of raw and thermally treated samples. Potato cultivars Birgit and Lady Claire were peeled, sliced and treated with 1% sodium chloride solution (SC) or 2% sodium ascorbate solution (SA). The samples were packaged in vacuum and modified atmosphere, MAP (10% CO_2, 3% O_2 and 87% N_2) and stored for 10 days at 3 and 10 °C. During storage, total and soluble dry matter content, pH, CIELab color parameters, texture, O_2 and CO_2 content within the package, number of aerobic mesophilic bacteria, and number of *Enterobacteriaceae* in raw samples were analyzed.In the third part, the influence of cultivar, tubers age, storage time and type of thermal treatement on phenolics, sugars and acrylamide content in the MPP samples were investigated. The content of phenolics and acrylamide was analyzed by ultra-performance liquid chromatography-tandem mass spectrometry (UPLC MS^2) and the content of sugars by high performance liquid chromatography (HPLC). Furthermore, fried samples were also analyzed for the content of polycyclic aromatic hydrocarbons (PAHs) by donor-acceptor complex chromatography (DACC).

It was concluded that cv. Birgit was more acceptable for the production of MPP in comparison with cv. Lady Claire. Treatment with SA solution and vacuum packaging were more effective in MPP preserving than the treatment with SC solution and MAP providing product safety and quality as well as sensory properties of the samples until the 8^{th} day of storage. The storage temperature (3 or 10 °C)did not have an important role on the shelf-life of the samples. The tubers age affected the physical properties of raw MPP (dry matter content, pH, color and texture) and taste of cooked MPP.However, such a conditions did not have a significant effect on the characteristic odor of raw and cooked MPP or taste of fried and baked MPP. The content of total phenolics was higher in cv. Lady Claire and it decreased during MPP storage. The content of sugars was higher in cv. Birgit. During tubers aging, the content of sugars increased, while storage time of MPP did not affect the amount of sugars.The content of phenolics and sugars was the highest in raw samples, while it was the lowest in cooked samples. The content of acrylamide increased with the age of tubers and MPP storage time.The content of PAHs was higher in the cv. Lady Claire and in MAP samples.Regardless of investigated sources of variation, the level of acrylamide and PAHs were under the limits according to the official regulation. In general, all samples were microbiologically acceptable.

Keywords: Birgit, Lady Claire, minimally processed potato, browning, packaging, tubers age, phenolics, sensory properties, sugars, acrylamide, PAH

SAŽETAK

Cilj ovoga rada bio je ispitati utjecaj sirovog krumpira (sorte Birgit i Lady Claire) tijekom starenja, uvjeta proizvodnje (primjena sredstva protiv posmeđivanja, uvjeti pakiranja) i uvjeta skladištenja na kvalitetu i sigurnost kao i senzorska svojstva minimalno procesiranoga krumpira (MPK) (sirovog i naknadno termički tretiranog). Istraživanje opisano u doktorskome radu se sastoji od tri dijela. Prvi i drugi dio rada obuhvaćaju istraživanje utjecaja sorte, starosti gomolja, sredstava protiv posmeđivanja, uvjeta pakiranja, temperature i vremena skladištenja MPK na kvalitetu i senzorska svojstva sirovih i termički obrađenih uzoraka. Krumpir sorti Birgit i Lady Claire je oguljen, narezan na ploške i tretiran 1% otopinom natrijeva klorida (SC) ili 2% otopinom natrijeva askorbata (SA). Isti uzorci pakirani su u vakuumu i modificiranoj atmosferi (10% CO_2, 3% O_2 i 87% N_2), skladišteni 10 dana pri temperaturi 3 i 10°C. Tokom skladištenja izuzimani su sirovi uzorci u kojima je analiziran udio ukupne i topljive suhe tvari, pH, parametri boje (CIELab) i teksture, udio O_2 i CO_2 unutar pakovine, broja aerobnih mezofilnih bakterija i broj *Enterobacteriaceae*. U trećem dijelu istraživanja ispitan je utjecaj sorte, starosti krumpira, duljine skladištenja i načina termičke obrade MPK na udio fenola i šećera u svim uzorcima te akrilamida u prženim uzorcima. Udio fenola i akrilamida je analiziran primjenom tekućinske kromatografije ultra visoke učinkovitosti s masenom spektrometrijom (UPLC MS^2), a udio šećera tekućinskom kromatografijom visoke učinkovitosti (HPLC).Također, u prženim uzorcima je analiziran udio policikličkih aromatskih ugljikovodika (PAH) pomoću DACC (donor-acceptor complex chromatography) metode.

Zaključeno je da je sorta Birgit prihvatljivija za proizvodnju MPK u odnosu na sortu Lady Claire. Bolji učinak u očuvanju kvalitete MPP je pokazalo tretiranje otopinom SA (2%) i pakiranje u vakuumu u odnosu na tretiranje SC (1%) i MAP uvjete.Uzorci tretirani otopinom SA i pakirani u vakuumu su bolje očuvani te su prihvatljive kvalitete i senzorskih svojstava do 8. dana skladištenja dok temperatura skladištenja nema značajnu ulogu u očuvanju uzoraka. Starost krumpira je utjecala na fizikalna svojstva sirovog MPK (udio ukupne i topljive suhe tvari, pH, boju i teksturu) i okus kuhanoga MPK, međutim nije imala značajan utjecaj na karakteristični miris sirovog, kuhanog, prženog i pečenog krumpira kao niti na okus prženog i pečenog MPK. Udio ukupnih fenola je viši u sorti Lady Claire i opada tijekom skladištenja MPK. Udio šećera je viši u sorti Birgit.Starenjem gomolja raste udio šećera dok vrijeme skladištenja MPK nije utjecalo na udio šećera. U sirovim uzorcima udio fenola i šećera je najviši dok je najniži u kuhanim uzorcima. Koncentracija akrilamida povećava se starenjem krumpira i skladištenjem MPK. Udio PAH-ova je viši u sorti Lady Claire i u MAP uzorcima. Neovisno o primjenjenim uvjetima istraživanja, udio akrilamida i PAH-ova je bio ispod maksimalno dozvoljene granice propisane zakonskim odredbama. Svi uzorci su bili mikrobiološki ispravni.

Ključne riječi: Birgit, Lady Claire, minimalno procesirani krumpir, posmeđivanje, pakiranje, starost gomolja, fenoli, senzorska svojstva, šećeri, akrilamid, PAH-ovi

I would like to thank my supervisor Branka Levaj, Ph.D., Full Professor for professional help, mentorship and selfless support during entire Ph.D. study. When I became Ph.D. student, I wished to have a supervisor like her and I am glad that my wish came true. I hope that we will stay in touch and cooperate in the future.

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A big thank you to my little daughter Ema. She is the wind in my back and extra strength and persistence. I hope one day she will be proud to be my daughter.

INFORMATION ABOUT THE SUPERVISOR

Ph.D. Branka Levaj, Full Professor

Ph.D. Branka Levaj, Full Professor was born on June 5th, 1959 in Zadar. In 1981 she graduated at Faculty of Food Technology and Biotechnology, University of Zagreb, where she also obtained her Masters of Science in 1987. and defended her doctoral thesis in 1998. She received her habilitation in the same institution in 2000.

After completeing her graduate study, she was employed at the Faculty of Food Technology and Biotechnology, University of Zagreb as: Young researcher (1982-1983); Associate (1983-1987); Research Assistant (1987-1999); Senior assistant (1999-2000); Assistant professor (2000-2005); Associate professor (2005-2011); Full professor (2011-2016); Full professor in a permanent position (2016-today). She has been the Head of the Laboratory of Chemistry and Technology of fruits and vegetables since 2003.

Branka Levaj earned Cohran fellowship and was scientifically trained in the United States Department of Agriculture, Eastern Regional Research Center, Philadelphia, USA from 1988 to 1989. Her main topics of interest include chemistry and technology of fruits and vegetables and changes of certain chemical constituents as biological active compounds during processing and storage. She is the coordinator of 5 courses and collaborator of 6 courses in the undergraduate, graduate and postgraduate studies. She supervised more than 120 graduate theses, 2 master theses and 4 doctoral theses. Further, she was the leader or collaborater of more than 10 scientific or professional national projects, and collaborator of 2 international scientific projects and she is the leader of 1 bilateral project.

Prof. Ph.D. Branka Levaj was in organization committee of several scientific meetings.

From 2003-2007 she was Vicedean for education and in 2006 she got „Acknowledgment of longstanding cooperation and outstanding contribution to the promotion of higher education, science and profession" regarding the 50th anniversary of studies of Food Technology, Biotechnology and Nutrition. Further, she was the Head of master study program Food Engineering, ECTS coordinator and President of the quality management committee as well as member of Committee for biotechnical science of Agency for Science and Higher Education. She is also member of Editorial board of the scientific journal Food Technology and Biotechnology.

She has published more than 80 scientific papers of which 32 are indexed in web of science and 22 in others databases.Other papers were published in the Proceedings of the international and national conferences and meetings. She also wrote several professional -popular papers and reviewed more than 100 manuscripts for scientific journals.

Authors publications included in the doctoral dissertation:

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Dite Hunjek, D., Repajić, M., Ščetar, M., Karlović,S., Vahčić,N., Ježek,D., Galić, K., Levaj, B. (2020) Effect of Anti-Browning Agents and Package Atmosphere on the Quality and Sensory of Fresh-Cut Birgit and Lady Claire Potato during Storage at Different Temperatures. *J. Food Process. Preserv*. **44,**1-15.doi:10.1111/JFPP.14391

Publication No. 2

Dite Hunjek, D., Pranjić, T., Repajić, M., Levaj, B. (2020) Fresh-cut potato quality and sensory: Effect of cultivar, age, processing and cooking during storage. *J. Food Sci.* **85,** 2296-2309.doi:10.1111/1750-3841.15353

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Table of Contents

List of abbreviations

ABA- anti-browning agent

BOPP - biaxially oriented polypropylene

CO_2 - carbon dioxide

DW - dry weight

EDTA -ethylenediaminetetraacetic acid

EFSA - European Food Safety Authority

FW - fresh weight

GAE - gallic acid equivalent

GMP- guanosine monophosphate

GRAS - Generally Recognized as Safe

HACCP - Hazard Analysis and Critical Control Point

H_2O - water

HPLC - high performance liquid chromatography

IFPA - International Fresh Cut Product Association

LDPE - low-density polyethylene

MA - modified atmosphere

MANOVA - multivariate analysis of variance

MAP- modified atmosphere packaging

MPFV- minimally processed fruits and vegetables

MPP - minimally processed potato

N_2 - nitrogen

O_2 - oxygen

PAH - polycyclic aromatic hydrocarbons

PAL - phenylalanine ammonia lyase

PA/PE - polyamide/polyethylene

PCA - Principal Component Analysis

PE - polyethylene

PP - polypropylene

PPO - polyphenol oxidase

PVDC - polyvinylidene chloride

RNA - ribonucleic acid

SA- sodium ascorbate

SC - sodium chloride

SS - soluble solids

TS - total solids

UPLC MS^2 – ultra-performance liquid chromatography - tandem mass spectrometry

USDA - United States Department of Agriculture

VA- vacuum packaging

General Introduction

Potatoes are one of the most popular foods worldwide. According to the research by Harper (1963), conducted on 432 respondents, only less than 1% of respondents do not like to eat potatoes. Potato is also a natural source of a large number of nutritive components such as starch, dietary fiber, amino acids, minerals, vitamins, and phenolic compounds (Akyol et al., 2016). It can be prepared for consumption in various ways including baking, boiling, roasting, frying, steaming, and microwaving (Jansky, 2010).

Minimally processed fruits and vegetables (MPFV) are the youngest group of fruit and vegetable products. According to the definition of the International Fresh-cut Produce Association (IFPA) (1999), MPFV are fruits or vegetables physically modified, but still fresh or cleaned and 100% usable, packaged, with high nutritional value, convenience and unchanged taste that retains its freshness. In the recent years due to the accelerated lifestyle in the developed countries, the production of minimally processed potatoes (MPP) increased. However, MPP is a product prone to texture, color, odor and taste changes as well as microbiological spoilage during storage. Therefore, it requires special conditions for processing and storage of raw materials as well as final product which is characterized with very short shelf-life.The preservation of sensory properties, safety and prolongation of the shelf-life of MPP can be influenced by selection of the appropriate potato cultivar, the use of anti-browning agents (ABA), packaging in appropriate packaging material and/or method, and storage at lower temperatures.

ABAs are substances that prevent the enzymatic reactions of potato browning in the presence of O_2. Some of the most well-known ABA are citric and ascorbic acid, cysteine and sulfites, although sulfites have recently been avoided due to their adverse health effects (Peroni and Boner, 1995; Bobo-García et al., 2020).Since consumers prefer more natural and nutritional foods, ABA such as green tea extract, garlic extract, *Capsicum* sp. (chili pepper) extract, *Citrus* sp. (lemon) extract, *Beta vulgaris* (Red beet) extract, heated onion extract, mate extract, rosemary and onion essential oils, and rice bran extract have recently been explored (Bobo-García et al., 2020).

An important factor in maintaining the food quality and safety is type of packaging. Proper selection of packaging materials and packaging method [e.g. vacuum packaging (VP) or modified atmosphere packaging (MAP)] preserves the sensory properties of food and prolongs the shelf-life of the product (Gorris and Peppelenbos, 1992).

Also, the great impact on the physical, chemical and sensory properties of MPP has potato aging. Depending on the storage conditions and storage time, sensory properties,

especially texture, and chemical composition of the potatoes, such as content of sugars, dry matter, phenolics, etc., are changing. These changes have a significant impact on the quality of potatoes during heat treatment (Kumar et. al., 2004; Wustman and Struik, 2007; Kaul et al., 2010,Rotim, 2010).

Compounds such as reducing sugars interact with amino acids, due to the Maillard's reactions, which leads to the formation of dark color pigments as well as odor and taste during frying (Jansky, 2010). One of the products of the Maillard's reactions is also the potentially carcinogenic compound-acrylamide. Acrylamide has been the focus of European Food Safety Authority (EFSA) monitoring over the last decade, and its concentration in food tend to be reduced to a minimum (EFSA, 2015). In addition to acrylamide, one of the harmful mutagenic contaminants which could be found in fried foods are polycyclic aromatic hydrocarbons (PAHs). Raw potatoes and frying oil can be the source of PAHs or they can be formed during frying (Abou-Arab et al., 2014; Samsøe-Petersen et al., 2002; Wennrich et al., 2002; Zhong and Wang, 2002). The European Commission(EC) (2011) defined permissible limit values for these contaminants in food: maximum permitted amount of PAHs is 2 μg kg^{-1} in oils for human consumption or used as ingredients and 10 μg $kg^{-1}$for benzo(a)pyrene or PAH4 group[benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene and chrysene].

Phenolics are compounds that are considered as bioactive components. Their production is a plant response to biotic or abiotic stresses. Their concentration in potatoes is conditioned by cultivar, agrotechnical processes, harvest and post-harvest treatments, storage conditions after harvest, processing and cooking methods (Akyol et al., 2016).

The aim of this study was to examine the impact of raw potato (cv. Birgit and Lady Claire) during aging, processing conditions (applied anti - browning agent, packaging conditions), and storage conditions on the quality and safety as well as sensory properties of minimally processed potatoes (MPP) (raw and subsequently thermally treated). This disertation is written in form of published papers with theoretical part, general discussion and conclusions.

Chapter 1

Theoretical background

- **Potato (*Solanum tuberosum*) - main features**
- **Minimally processed potato**
- **Influence of cultivar and potato aging on its physical, chemical and sensory properties**
- **Browning reactions and anti-browning agents**
- **Packaging**
- **Influence of thermal treatment on physical, chemical and sensory properties of minimally processed potato**
- **Hypothesis, research objectives, and expected scientific contributions**

1. Potato (*Solanum tuberosum*) - main features

The potato (*Solanum tuberosum* L.) is the fourth largest food crop in the world after rice, wheat and maize (Akyol et al., 2016). The largest potato producer in the world is China with 90.3 Mt of potatoes produced in 2018 followed by India and Russia (FAOSTAT, 2020). According to the statistical data of the Croatian Bureau of Statistics (2019) 182 261 t of potato were produced in Croatia during 2018.

Potatoes originate from South America, more precisely from the Andes in the area of Peru and Bolivia. It was first brought to Europe in Spain around 1570, and a little later, around 1590 in England, after which it spread to all other parts of the world (Hawkes, 1992).

Potato is a plant that belongs to the Solanaceae family, and the genus *Solanum*. It includes about 2000 different species of which eight of them are cultivated and these are *Solanum stenotomum, Solanum phureja, Solanum ajanhuiri, Solanum goniocalyx, Solanum chaucha, Solanum juzepczukii*, *Solanum curtilobum* and *Solanum tuberosum*. The species *Solanum tuberosum* is divided into subspecies *andigena* (cultivated in South and Central America) and subspecies *tuberosum* cultivated all over the world. More than 3 000 cultivars of potatoes are known, of which 700 are used in cultivation (Lisińska and Leszczyński, 1989).

Potatoes can be propagated vegetatively, which is the most often, and generatively from seeds in breeding. The potato plant has a green stem with leaves that reaches a height of 30-80 cm. During the flowering period, pentamerous flowers are formed on the stem, white, blue or purple color, depending on the cultivar. Over time, the flower develops into berries with double chambers containing up to 200 seeds. Shoots, i.e.stolons, continue on the stem below the ground. They are 5-30 cm long and 2-3 mm thick (Figure 1) (Lisińska and Leszczyński, 1989).

Tubers are formed from the top of the stolon. They are a storage organ of potato plant. One plant can form 4-20 tubers. Tuber contains bud end and stem end. On the surface of the tuber there are hollows called eyes. The tuber consists of pith, parenchyma, vascular system (ring), cortex and the skin of periderm (Figure 2). After the interruption of the dormant phase, sprouts are formed from the buds of the tubers, from which a new plant can be formed (Lisińska and Leszczyński, 1989).

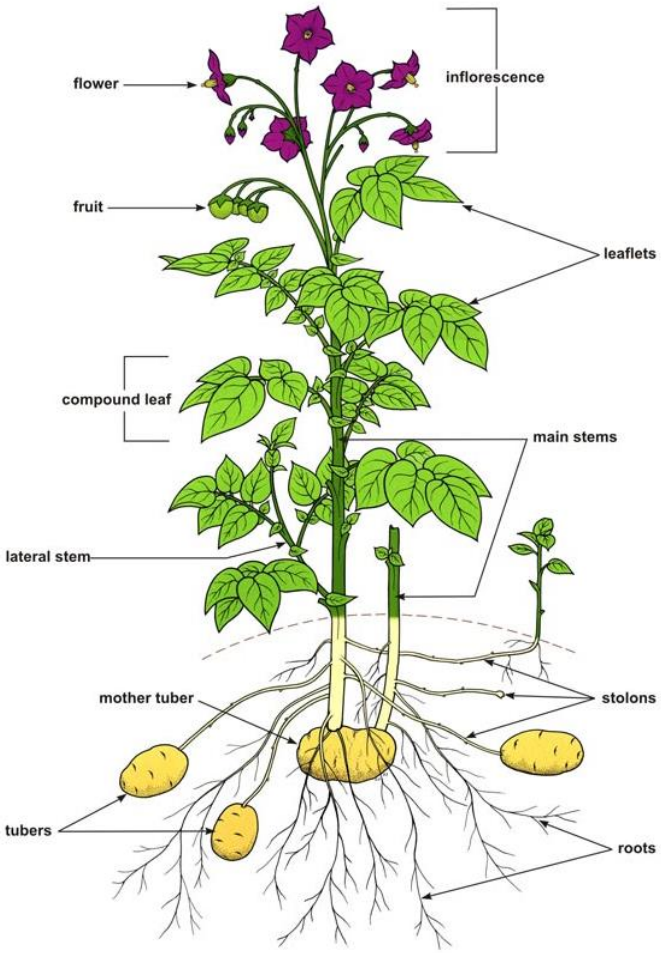

Figure 1. The parts of potato plant (CIP, 2020)

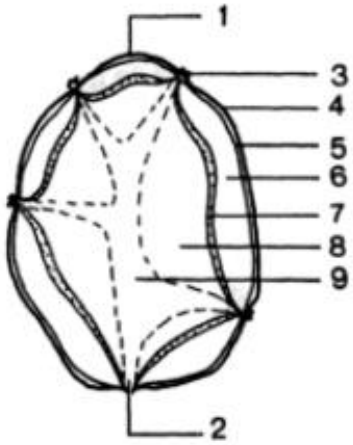

Figure 2. Principal structural features on tuber longitudinal section (1- bud end; 2-stem end; 3- eye; 4- periderm (skin); 5- cortex; 6- parenchyma; 7- vascular ring; 8- parenchyma; 9- pith) (Lisińska and Leszczyński, 1989).

Potatoes grow best in the area where the average daily temperature is between 5 and 21 °C. The most appropriate soils for growing potatoes are sandy-humus and sandy-loam soils that are crumbly in structure, permeable, loose and rich in minerals and organic matter with pH 5.4 - 6.5. Necessary macronutrients for potatoes growing are nitrogen (N), phosphorus (P) and potassium (K). In addition to the above, a sufficient amount of water is needed for a good yield of potatoes. Therefore, potato fields are often irrigated. During potato cultivation, it is necessary to pay attention to the crop rotation. To prevent the infestation of harmful pests and the spread of disease, potatoes can be planted on the same plot every 3rd or 4th year. Potatoes are planted in mounds to a depth of 8-12 cm. Depending on the size of the seed potato fraction, the distance between planted plants is from 25 cm to 50 cm (Parađiković, 2002; Vreugdenhil, 2007).

Potato cultivars differ mutually according to the morphology of the plant and the morphology and chemical composition of the tubers. They can also differ in terms of biochemical properties, growth physiology, resistance to bacteria, viruses and other pests, and diseases. One of the important cultivar characteristics is the length of the maturity period, i.e. period from planting and sprounting until harvesting, which varies between 60 and 200 days. (Lisińska and Leszczyński, 1989). Accordingly, potato cultivars are divided into several groups (Camire et al., 2009):

- very early: 65-70 days
- early: 70-90 days
- medium: 90-100 days
- late: 110-130 days
- very late: > 130 days

In regard to the application, potato cultivars can be distinguished as ones intended for retails as fresh, so-called table potato and ones intended for industrial processing. Table potatoes are often early cultivars that have a lower level of dry matter (total solids) and starch, while industrial cultivars are often late cultivars that contain a higher level of dry matter and are suitable for frying and production of chips, pommes frites, etc.(Lisińska and Leszczyński, 1989). Moreover, for culinary purposes, cultivars are often divided by their waxiness on floury or mealy potatoes with 20–22% starch and waxy boiling potatoes with 16–18% starch. Potato cultivars can also be distinguished depending on the composition of amylose and amylopectin. Potato cultivars that contain a higher proportion of amylose are more suitable for the production of mashed potatoes than cultivars of potatoes that contain a higher

proportion of amylopectin because such potatoes retain their shape after cooking (Dresser, 2007).

Potato cultivars are produced with targeted characteristics (disease resistance, high yield, adaptation to a particular climate, dry matter content, etc.) to satisfy the producers and customers. If a particular cultivar does not meet the needs of the market, it is deleted from the cultivar list and is no longer cultivated (Lisińska and Leszczyński, 1989).

The chemical composition of potatoes depends on the cultivar, cultivation year, growing area, potato age and type of preparation. According to the United States Department of Agriculture (USDA), peeled boiled potato which were boiled unpeeled contains about 77% water and 23% dry matter, where the starch is the most abundant (about 19%), followed by mono- and disaccharides (glucose, fructose and sucrose), which are present about 1.5%, proteins (2%) and fats (0.1%) (USDA, 2020).

For potato growers and the processing industry, dry matter content of potatoes is extremely important. The dry matter content in tubers depends on environmental factors during the growth of the plant and development of the tuber, such as intercepted solar radiation, soil temperatures, available soil moisture and cultural treatments. The dry matter content affects the sensory properties, particular the texture of the final product after processing. Also, depending on the dry matter content, it is determined whether the potatoes are suitable for cooking (waxy or mealy texture) or baking. Tubers with a higher dry matter content (more than 18-20%) are suitable for bruising during harvesting (Vreugdenhil, 2007; Anonymous 1, 2020). The total dry matter also contains a proportion of soluble solids. The soluble solids in potatoes consist of sugars (glucose, fructose, sucrose), starch, proteins, etc. (Maruf et al., 2019).

The most common sugars in potatoes are monosaccharides, i.e. reducing sugars glucose (0.15 - 1.5%) and fructose (0.15 - 1.5%), and disaccharides, i.e. non-reducing sugar sucrose (0.4 - 6.6%). The composition of sugars in potatoes varies depending on the cultivar, the physiological status of the tubers, external factors during growth in the field, potato age and storage conditions after harvest (Vreugdenhil, 2007; Cabezas-Serrano et al., 2009). The level of reducing sugars in potatoes that are acceptable for processing is 0.2-0.3% in chips production and 0.3 - 0.5% in French fries (Vreugdenhil, 2007). The large amount of sugars in potatoes is undesirable because it contributes to the formation of brown color, bitter taste and the formation of acrylamide due to the Maillard's reactions during potatoes frying (Kumar et al., 2004). The content of sucrose above 1% in table potato is undesirable due to the formation of an unacceptable sweet taste during cooking of potatoes (Vreugdenhil, 2007).

In potatoes there are 19 amino acids present, including all 10 essential ones (methionine, tryptophan, histidine, threonine, isoleucine, phenylalanine, arginine, leucine, lysine, valine) and cysteine, tyrosine, glycine, alanine, proline, serine, glutamic acid and aspartic acid. Cysteine is present in a minimum (24 mg $100g^{-1}$) and aspartic acid in the maximum amount (457 mg $100g^{-1}$). In addition, potato contains phenolic compounds and carotenoids, which, as well as vitamin C, show antioxidant activity and thereby have a positive effect on health (bioactive compounds) (Tian et al., 2016).

The content of bioactive compounds in the potato is relatively small and it significantly depends on the treatment and applied temperatures, but due to frequent consumption in large amounts, potato is a good source of antioxidants (Song et al., 2010; Liu, 2013). As mentioned previously, bioactive compounds include phenolics, secondary metabolites that are synthesized by plants for protection from various biotic and abiotic stresses. Some compounds also have antibacterial properties (Sepelev and Galoburda, 2015; Susarla, 2019). The content of phenolic compounds is dependent on agrotechnical processes, climatic conditions, ripeness during harvest, post-harvest manipulations, genotype, storage conditions after harvest, processing and cooking methods. Most of the phenolics are accumulated in the tuber peel, although phenolics are also present in tuber flesh. Phenolics present in potatoes are phenolic acids and flavonoids (flavonols, flavanols and anthocyanins). The most common representative of phenolic acids in potatoes is chlorogenic acid, the concentration of which includes 90% of the total concentration of phenolics (17.3 - 1468.7 mg 100 g^{-1} dry extract) (Mäder et al., 2009;Akyol et al., 2016). In addition to chlorogenic acid, ferulic acid, gallic acid, *p*-coumaric acid, syringic acid, vanillic acid, sinapic acid, and salicylic acid are also present in potatoes. Flavonoids affect the taste and color of potatoes. The most common flavonoid in potatoes is catechin (0-1.5mg 100 g^{-1} dry extract) (Mäder et al., 2009; Akyol et al., 2016). Quercetin, kaempferol rutinose, rutin and epycatechin are other flavonoids also present in potatoes (Akyol et al., 2016; Susarla, 2019). The content of flavonoids in white potatoes is higher than 30 mg 100 g^{-1} fresh weight, while in red and purple potatoes, this concentration is doubled due to high concentration of anthocyanins (Akyol et al., 2016).

The color of the tubers is affected by the proportion of anthocyanins and carotenoids. Purple tubers contain a higher proportion of anthocyanins. Although their peel is pink or red, the flesh of the tuber can be yellow or white, depending on the cultivar characteristics. The yellow color of the tuber is contributed by the proportion of carotenoids in the tuber.Carotenoid content in potatoes vary from 50 to 100 µg 100 g^{-1} weight in white cultivars, while in yellow and orange potato cultivars it is up to 2000 µg 100 g^{-1} weight.The carotenoids

that contribute to yellow potato flesh belong to the group of xanthophylls (Vreugdenhil, 2007). The most common carotenoids in potatoes are violaxanthin, lutein and lutein 5-6 epoxide, while zeaxanthin is present in low concentrations. However, zeaxanthin and antheraxanthin predominate in tubers with pronounced yellow color of the flesh. Violaxanthin, antheraxanthin, lutein and zeaxanthin are dominant in less pronounced yellow flesh tubers, while violaxanthin, lutein and β-carotene predominate in creamy flesh-colored tubers (Burgos et al., 2012).

Potatoes also produce glycoalkaloids, secondary metabolites that are toxic to humans, animals, microorganisms, insects and viruses. The most common glycoalkaloids are α-olanine and α-chaconine (Sepelev and Galoburda, 2015).These compounds are heat-stable and decompose at temperatures between 230 and 280°C and therefore are not removed during boiling and frying. The amount of glycoalkaloids in potatoes considered generally recognized as safe is 200 mg kg^{-1} of fresh weight (Bejarano et al., 2000) although total glycoalkaloids level in commercial cultivars is in range 2-10 mg kg^{-1} fresh weight (Vreugdenhil, 2007). Many stressors during cultivation, harvesting and storage affect the increase in glycoalkaloids concentration. Increased concentration of glycolacoids is first recognized in green and inmature tubers. Exposure of tubers to light also affects the increase in concentration of glycoalkaloids (Bejarano et al., 2000).

2. Minimally processed potato

MPFV belong to the youngest group of fruit and vegetable products. According to the definition of the IFPA (1999), MPFV are fruits and vegetables physically modified, but still fresh or cleaned and 100% usable packaged with high nutritional value, convenience and unchanged taste that retains its freshness. In addition to minimally processed apples, watermelons, pineapples, lettuce, rocket, radishes and carrots, the presence of MPP on the market (Figure 3) has been growing in recent decades. This is supported by the fact that in the United States, in period between 1965 and 1995/1998, the time required to prepare meals was reduced by 38.6%. Moreover, 64% of men and 35% of women aged 21-64 stated that there was no time for food preparation in their household (Jabs and Devine, 2006). On the Croatian market, MPP is still represented in small quantities, most often within the food program of hotels, restaurants and cafes (HORECA).

Figure 3. Examples of MPP from the market (Anonymous 2, 2020; Anonymous 3, 2020; Anonymous 4, 2020)

Figure 4 shows general technological process of minimally processing of fruits and vegetables which also describes minimally processing of potato.

Processing starts with washing in order to remove soil, pesticide residues and other dirt from the surface of tuber. During washing, it is recommended to use 5-10 L of water kg^{-1} of potatoes (Rocculi et al., 2009). The water should be cold (below 5 °C) to prevent the growth of microorganisms on the line. To make the water microbiologically safe, various chemical and physical methods are used to suppress the growth of microorganisms. The use of GRAS (Generally Recognized as Safe) disinfectants such as organic acids, ozone, hydrogen peroxide (H_2O_2) is mostly practiced. Convential disinfectants such as chlorine, due to the possibility of formation of carcinogenic compounds in contact with organic substances, and chlorine dioxide, due to their instability and explosiveness at high concentrations are avoided. Further, other disinfectants are being explored such as electrolyzed water and trisodium phosphate which could replace the conventional ones (Tapia et al., 2015).

Washing is followed by peeling, which can be applied in three types: mechanical peeling (carborundum drums), chemical peeling (immersion of potatoes in alkaline sodium

hydroxide solution (NaOH) or potassium hydroxide (KOH) at high temperatures of 90-100 °C), and peeling with high pressure steam (Rocculi et al., 2009; Tapia et al., 2015).

After peeling, the potatoes are cut and chopped. During cutting, it is preferable to use knives with a stainless steel blade, but it is also possible to use knives with carbon blades. Blades made of stainless steel are more suitable than blades made of carbon since carbon blades are brittle. Also, carbon releases iron ions into water causing corrosion of the blades (Rocculi et al., 2009).

Due to peeling, cutting and chopping, it is necessary to rinse the potatoes with water of temperature below 5 °C in order to remove surface microorganisms and cellular fluids (Rocculi et al., 2009). Due to these actions, even during peeling, the cell walls of potatoes are damaged and starch and enzymes such as polyphenol oxidase (PPO) react with O_2 and cause a browning of the potato surface by transforming phenolic compounds into quinones which are converted into melanoids by further chemical reactions (Whitaker and Lee, 1995). It is important that the blade of knife or cutter is sharp in order to avoid bruising and similar damage on the tuber caused by blunt knives. It is necessary to change the blades of the knives with frequent dynamics - every hour (Rocculi et al., 2009).

To prevent browning of potatoes, ABAs are added to water (Rocculi et al., 2009) what will be discussed in more detail in the next chapter.

After washing, excess surface water on the potatoes is removed by passing the potatoes through a centrifuge or drying the potatoes in an air tunnel (Rocculi et al., 2009).

MPP is packed in appropriate packaging in a separate room, separated from the rest of the process and cooled to temperature of 1-2 °C (Rocculi et al., 2009) Packaging will be also discussed in more detail in the next chapter.

After packaging, MPP is stored at temperature of 5 - 10 °C (Rocculi et al., 2009), at which the respiration rate decreases (Ghazavi and Houshmand, 2010) and other processes that cause a decrease in product quality.

The most important characteristics of MPP on the basis of which the customer decides whether to buy the product or not is the color and texture of MMP (Barrett et al., 2010). The MPP must be of bright appearance with flesh color characteristic for the cultivar from which it was produced without symptoms of darkening (Tudela and Gil, 2020). Therefore, it is important to prevent enzymatic browning of MPP by selecting the optimal ABA and packaging (Ahvenainen, 1996; Rocculi et al., 2009;). Also, it is necessary to handle the potatoes carefully during harvesting, in order to prevent the appearance of bruises (Kumar et al., 2004). The selected potato cultivars and tubers age have a great influence on the color

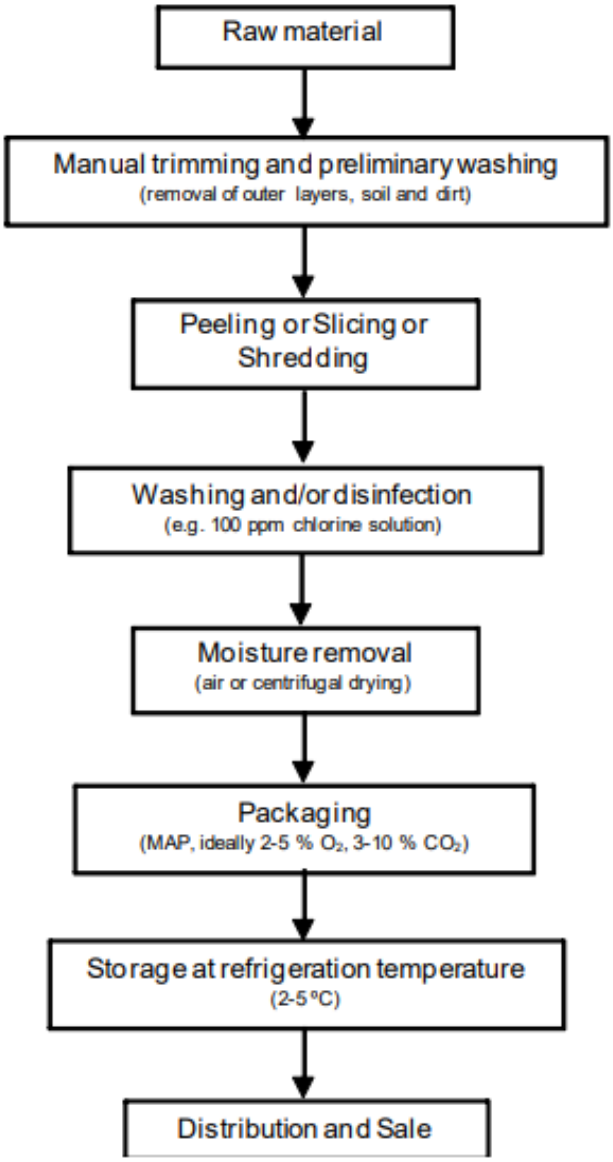

Figure 4. A flow diagram for the production of minimally processed fruits and vegetables (Oliveira et al., 2015)

of MPP (Cabezas-Serrano et al., 2009; Silveira et al., 2017). Potato color is most often determined by colorimeters or image analysis using a XYZ, RGB or L^* a^* b^* color spaces (Rocculi et al., 2009). Parameter L^* is a measure of light, expressed in values from 0 (black) to 100 (white). The parameter a^* is a measure of green (-) to red (+), while b^* parameter is a measure of blue (-) to yellow (+). Using parameters, a^* and b^* it is possible to calculate values for color tone ($H°$) and intensity or color saturation (C^*) (Calder et al., 2011b; Cornacchia et al., 2011).

MPP texture must be firm, slightly moist without symptoms of dehydration (Tudela and Gil, 2020). The MPP texture largely changes due to water loss from the product. During peeling and cutting of potatoes, the protective periderm is damaged and area through which water is lost increases. Due to water loss, a decrease in turgor, disintegration of the cell walls, leakage of cell juices and softening of the tissue occur (Rocculi et al., 2009). Endogenous enzymes on the cell walls and growth of microorganisms also contribute to tissue softening (Rocha et al., 2003). Sometimes MPP tissue hardens, especially in pre-peeled potatoes, due to cross-linking cell wall components and suberin accumulation. Hardness of potatoes can be avoided if the potatoes are cooked and prepared for consumption a few hours after peeling (Rocculi et al., 2009). The change in texture is influenced by the length of storage, the application of ABA and the type of packaging (Rocculi et al., 2009; Calder et al., 2011a; Rizo et al., 2018). The results of Rizzo et al. (2018) indicate that the firmness of MPP samples packaged in *sous vide* type packaging and treated with rosemary oil decreases over time. In a study by Rocha et al. (2003), the firmness of the MPP samples packaged in vacuum decreased after the first day of storage and after that, during 6 day of storage, remained constant. ABA agents that are prone to water absorption such as calcium chloride have the effect of increasing the firmness of potatoes (Rocculi et al., 2009). Acids used as ABA agents dissolve and redistribute calcium and magnesium in potato tissue which are responsible for the crosslinking of cell wall pectin which makes the tissue softer (Calder et al., 2011a).

Because of the slightly acidic pH (5.8 - 6), high humidity and large cut surface, MPP is an ideal substrate for the growth of bacteria, yeasts and moulds (Ahvenainen, 1996). Raw potatoes come into contact with microorganisms even when the potatoes are in the soil. During minimal processing, due to the exposure of the raw material to air, water, dirty surfaces and insufficient hygiene of the workers, the product can be additionally contaminated (Rocculi et al., 2009). Therefore, it is extremely important to adhere to the principles of HACCP (Hazard Analysis and Critical Control Point) and good manufacturing practices during production of MPP (Ahvenainen, 1996). Pectinolytic microorganisms of the genera *Pseudomonas*, *Enterobacter* and microorganism *Clostridium butiricum* that soften MPP tissue begin the process of spoilage of MPP. Microorganisms that cause food spoilage are often in competition with pathogenic microorganisms in terms of O_2, space, carbohydrates and other nutrients and they can prevent their growth to dangerous limits (Gorris and Peppelenbos, 1992). Lund (1968) studied the presence of microorganisms on washed and peeled potato prior to sulfite treatment before and after storage at 6 and 23 °C. Microorganisms such as gram-positive cocci, gram-positive rods (coryneform and bacilli), fluorescent pseudomonas,

nonfluorescent oxidative organisms and *Enterobacter – Hafnia* sp., were isolated before storage, while after storage, *Enterobacter - Hafnia* sp. and *Erwinia herbicola* were predominant culture. Suppressing the growth of bacteria can be influenced by optimal packaging and storage of products at lower temperatures (< 5°C). However, even when MPP are stored at lower temperatures, psychrophilic pathogens bacteria such as *Listeria monocytogenes, Yersinia enterocolitica, Salmonella* spp. and *A. hydrophila* can survive (Ahvenainen, 1996). If anaerobic conditions are created within the MPP package, there will be an increase in anaerobic microorganisms such as *Clostridium botulinum, Listeria monocytogenes, Bacillus cereus, Salmonella typhimurium* and *Staphilococcus aureus* (Rocculi et al., 2009).Table 1 reports on microorganisms present on MPP during various minimall processing actions.

MPP is a food prone to changes in texture, color, odor and taste, as well as microbiological spoilage during storage, what leads to its short shelf-life. The shelf-life of the MPP and its quality and safety are affected by the selection of the appropriate potato cultivar, type of ABA, packaging material and method, disinfectants during the production process, and MPP storage temperature as well as tubers age.

Given the tendency to change sensory properties as well as rapid spoilage, the shelf-life of MPP is usually up to 7 days (Laurila et al., 1998; Rocculi et al., 2009).

Table 1. Microflora of MPP during various minimall processing actions (Rocculi et al., 2009)

Process	Storage temperature (°C)	APC[b] (log CFU)	Microflora isolated	Reference
P, C, D[a]	4, 7, 10	4,0 cm^{-2}	*Bacillus cereus, Enterobacter cloacae, Hafnia alvei, Klebsiella oxytoca, Pseudomonas fluorescens, Staphylococcus aureus,* coliforms	Giannuzzi and Zaritzky, 1990
P, C	25	6,2	*Staphylococcus aureus,* coliforms	Bryan et al., 1992
P	4	5,0	psychrotrophs, *Rhodotorula, Alternaria, Penicillum, Aspergillus, Cladosporium*	Giannuzzi and Zaritzky, 1993

[a]P, hand peeled C, cut; D, dipped;
[b] APC, aerobic plate count in log CFU g^{-1} raw potatoes

2.1. Influence of cultivar and potato aging on its physical, chemical and sensory properties

Proper selection of potato cultivar is one of the key factors in MPP production. Potatoes for the production of MPP must have uniform shape and size without defects and good organoleptic properties (texture, taste, odor and color). It is desirable that cultivar is suitable for longer storage periods and to be resistant to disease, mechanical tissue damage, elevated CO_2 content and low O_2 content as well as low respiration rate (Rocculi et al., 2009).

Also, it is necessary that the potatoes have a certain chemical composition or content of dry matter, reducing sugars, starch and phenolics. For this type of product, it is desirable to use potatoes that are less prone to enzymatic browning, i.e. potatoes that contain lower content of phenolics and have lower PPO enzyme activity, but higher antioxidant activity and higher content of sugars (Cabezas-Serrano et al., 2009). Some authors claim that the tendency to brown is affected by the concentration of amino acids (tyrosine, glutamine acid, asparagine and aspartic acid), the concentration of the chlorogenic acid and the activity of PPO (Sapers et al., 1989; Thybo et al., 2006).

Previous research has shown that the potential cultivars for MPP are (greater towards less sensitivity to browning) Monalisa>Spunta>Liseta> Cara> Agria (Cantos et al., 2002) and Marabel> Agata> Agria> Vivaldi>Almera (Cabezas-Serrano et al., 2009). Cornacchia et al. (2011) investigated the cultivars Safrane, Ariana, Liseta and Spunta. Cultivars Safrane, Ariana and Liseta cultivars proved to be suitable cultivars for the production of MPP because the color of the MPP was satisfactory, while cv. Spunta proved to be the least suitable. Silveria et al. (2017) investigated the influence of genotype, tubers storage time and cut type of cultivars Bruja, Michuñe roja, Michuñe azul and Asterix. Although all four cultivars proved to be acceptable for minimal processing, Bruja and Michuñe roja showed increased metabolic activity and tendency to browning and microbiological spoilage (Figure 5). Ierna et al. (2016) investigated the suitability of early potato cultivars for minimal processing by studying the physical, chemical and sensory properties of MPP after 9 days of storage at 4 °C. Cultivars Arinda, Marabel, Matador and Spunta showed to be the most suitable, which was not the case with the cultivars Antea and Ditta which manifested as unsuitable for minimal processing. Thybo et al. (2006) investigated the color change, sensory properties, and profile of aromatic compounds of the Marabel, Berber, Arkula, Agria, Folva, and Sava cultivars. During this research, cv. Agria and Folva proved to be more suitable for minimal processing, while cv.

Marabel, Berber and Sava did not give satisfactory results. Bobo-García et al. (2020) stated that cv. Agria, Marabel, Arinda or Marable are the most resistant to browning after minimal processing.

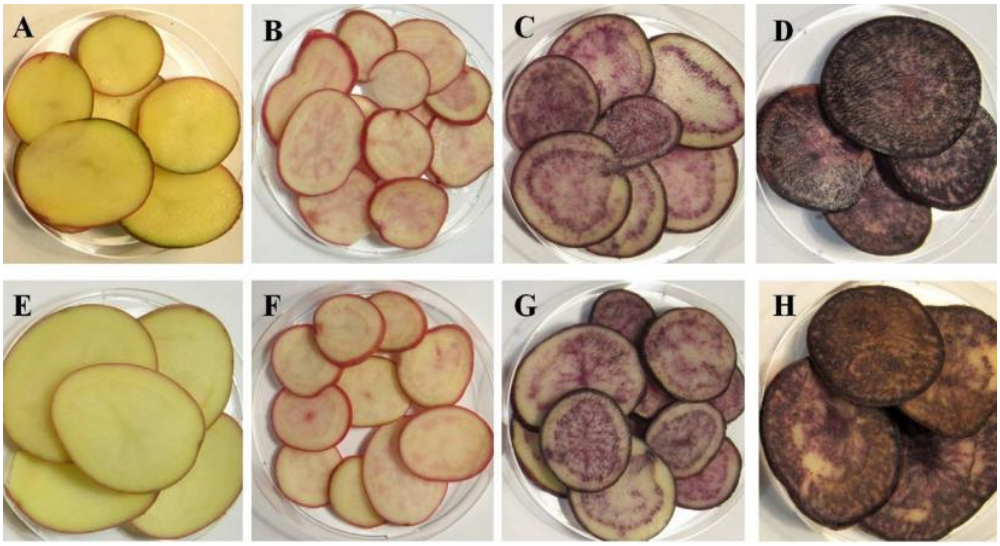

Figure 5. Asterix (A) Michuñe roja (B) Michuñe azul (C) and Bruja (D) chips produced with raw material stored for 2 months. Asterix (E) Michuñe roja (F) Michuñe azul (G) and Bruja (H) chips produced with raw material stored for 4 months (Silveira et al., 2017).

In the storage house, potatoes can be stored in bulk or in wooden boxes. After receiving, the potatoes are subjected to postharvest curring treatment. During this period, the potatoes are stored at 15 °C for 14 days and ventilated to allow healing damaged parts on the tubers and keep the potatoes in a dormant phase which is needed for longer storage.Curing tretament (approximately 10 days at 16°C immediatelly after harvest) improves color and sensory properties of MPP (Figure 6), increases the concentration of phenolic compounds such as chlorogenic acids, increases PPO activity and lowers phenylalanine ammonia lyase (PAL) activity (Wang et al., 2015). After the curing period, the storage temperature is lowered by 0.5 °C every day until optimal storage conditions (temperature, relative humidity, gas composition) are achieved for long-term storage. These actions are necessary to keep the potatoes in the dormancy phase and prevent the potatoes from sprouting, and to avoid stress on potatoes during storage. Namely, sprouting and stress increase the content of reducing sugars in potatoes, and reduce the starch content, i.e. dry matter, and therby the quality of potatoes. Table potatoes are usually stored at 3 °C, while industrial potatoes are stored at 6-10

°C (Vreugdenhil, 2007) with a relative humidity of more than 95% (Wustman and Struik, 2007). During storage, the tubers lose weight due to respiration as they consume starch to obtain energy. Also, tubers lose weight due to transpiration (water loss) (Wustman and Struik, 2007). Silveira et al. (2017) studied the influence of tubers storage time (2 and 4 months at 12°C and 90% relative humidity) of cv. Bruja, Michuñe roja and Michuñe azul on suitability for MPP. MPP which was produced from potato stored for 2 months exhibited 1 to 2.5-fold higher respiration rate than MPP produced from potatoes stored for 4 months, probably because potato was still in stress because of harvest. Dry matter decreased after four months of storage.

The content of reducing sugars during storage increases due to conversion of starch into sugars, which is especially pronounced if the potatoes are stored at lower temperatures (bellow cca 9°C) (Kaul et al., 2010; Ellis et al., 2019). This phenomenon is called „low temperature sweetening“ and it can cause a darker color, bitterness and contribute to the formation of acrylamide in fried products (Kumar et. al., 2004).

During storage, potatoes should be treated with anti-sprouting agents. It is important to prevent sprouting since active transpiration is present on the surface of the sprout and potato loses weight, firmness and gradually shrinks (Rotim, 2010). Moreover, starch is converted into reducing sugars during sprouting in order to provide enough food for the tuber and thereby enabling it to form a new plant.

Potato storage also affects the sensory quality and the aroma composition of MPP. Since the dry matter content decreases during storage, it is likely that MPP produced from potato tubers that have been in storage for a longer period cannot be used for frying due to excessive oil absorption (Silveira et al., 2017). Except dry matter, pH also decreases during storage, while reducing sugars increase (Jansky, 2010). The content of free amino acids in potatoes is also affected by the storage temperature. If the potatoes are stored at temperature of 10 °C, after 25 days the content of glutamine and asparagine increases. These free amino acids contribute to the development of the characteristic taste of potatoes. During storage, the level of total fatty acids increases which affects the concentration of volatile components of the flavor of baked potatoes since by boiling fatty acids degrade into aldehydes and ketones which contribute to the taste of boiled potato (Vreugdenhil, 2007; Jansky, 2010). By improper storage of potatoes, the content of glycoalkaloids in potatoes increases, which contributes to the bitter taste (Vreugdenhil, 2007).

Figure 6. The effect of postharvest curing treatment temperature on potato flesh browning. Curing - Fresh cut slices 12 days after cut which were influenced by curing (stored at 16 °C for 10 days then used for fresh cut, CK - potato stored at 3°C for 10 days and then used for fresh cut, without curing treatment. Picture was taken 12 days after cut (Wang et al., 2015)

2.2. Browning reactions and anti-browning agents

Enzymatic browning has the greatest impact on MPP quality. The first step that contributes to the development of enzymatic browning is damage of the plant's tissue membrane. After tissue damage or senescence, plant cells begin to decay and a complex of enzymes such as PPO and/or phenol peroxidase and O_2 is formed. Such complex in the reaction with phenolic substrates (phenolics, catechins) transforms phenolics into *o*-quinones. PPO enzyme belongs to the oxidoreductase family and catalyzes two different types of reactions, ortho-hydroxylation of monophenolics producing *o*-diphenols and oxidation of *o*-diphenols, producing *o*-quinones (Figure 7). The formation of *o*-quinone compounds is a reversible reaction in the presence of reducing agents, however they are very reactive molecules. They have the ability to condense rapidly and to enter into non-enzymatic reactions with groups of amino or sulfhydryl proteins and sugars resulting in the formation of red, brown or black polymers of high molecular weight and unknown structure called melanoidins. The intensity of melanoidins color is conditioned by different forms of quinone. The above mentioned non-enzymatic polymerization reactions, which is included in the

Maillard's reactions, are irreversible. The oxidation products of phenolic compounds can interact with proteins via covalent condensation. These reactions can lead to structural, functional and nutritional changes of proteins due to reaction of quinones with -SH and -NH amino acid groups. Proteins which contain phenolic tyrosine groups or are attached to a phenolic acid through a pseudo-peptide link are also a subject to modifications and can act as substrates for PPO (Bobo-García et al., 2020).

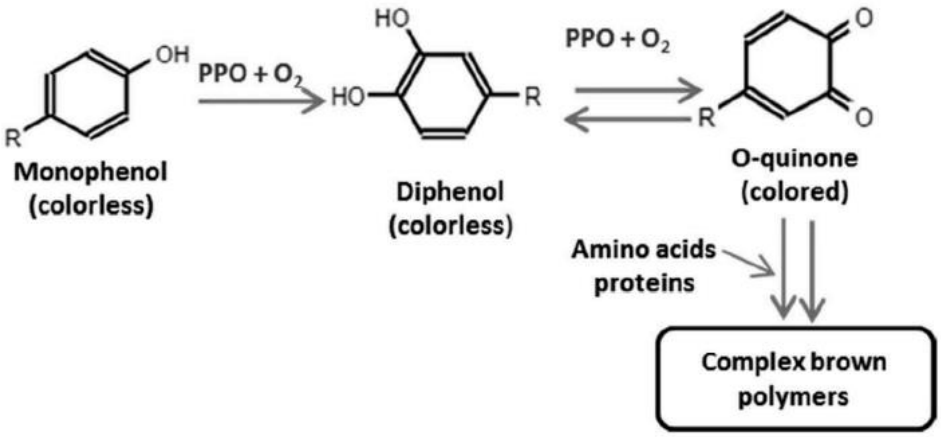

Figure 7. Schema of PPO reaction of enzymatic browning (Bobo-García et al., 2020)

Enzymatic browning can be prevented in several ways: by inhibiting the enzyme that catalyzes the enzymatic reaction, by removing the substrate from the reactions (phenolics or O_2), or by reacting with intermediates to prevent the formation of colored pigments (Bobo-García et al., 2020). Treatment with ABA efficiently prevents the enzymatic browning of potatoes. The described enzymatic reactions may be inhibited by ABA by reducing quinones to phenolics, lowering the pH which is optimal for the activity of the enzyme or having chelating properties that bind metal ions from the enzyme and thus inhibit them (Bobo-García et al., 2020). ABA should be inexpensive, easily accessible and they must not affect the sensory properties of the product. It is desirable that they have antimicrobial activity at the same time (Wang et al., 2015). Also, the duration of treatment and the concentration should be well assessed. After treatment with ABA and before packaging, MPP should be dried so that excess water on the potatoes would not cause microbial spoilage inside the package (Rocculi et al., 2009).

Well researched ABAs are citric and ascorbic acid. Citric acid is an acidulant and cooper chelating agent and is therefore often used in combination with another agent, while ascorbic

acid is an acidulant, quinone reducer, cooper chelating agent and a competitive inhibitor in enzymatic oxidation (Bobo-García et al., 2020). Ierna et al. (2016) concluded that 2% of citric acid + 2% of ascorbic acid have a positive effect on sensory, physical and chemical properties of MPP. Calder et al. (2011a; 2011b) examined the effect of sodium acid sulfate, citric acid, ascorbic acid, catechin and NatureSeal and found that the application of 3% sodium acid sulfate better prevents browning and hardening of the product and lowers PPO activity more effectively when compared to other ABA. Also, effective reducing agents are cysteine derivatives such as N–acetyl-L-cysteine and reduced glutathione which can be a good alternative to sodium sulfite (Bobo-García et al., 2020). Sulfites are less commonly used today due to the knowledge that they can cause bronchial asthma (Peroni and Boner, 1995).Cacacae et al. (2002) found a better efficacy of 5% erythrobic acid (isoascorbic acid) in combination with 1% citric acid in preventing browning and preserving sensory properties in comparison with the use of 1% N-acetyl-L-cysteine and 1% diethylene triamino pentaacetic acid. This can be supported by applying passive and active MA. Calcium chloride can also be used as an ABA. In addition to preventing browning, it also prevents softening of MPP during storage (Limbo and Piergiovanni, 2006).

Some other ABA compounds studied, such as 4-hexylresorcinol acts as an enzyme inhibitor (Bobo-García et al., 2020). Mattila et al., (1995) researched anti-browning properties of citric acid, ascorbic acid, calcium chloride, potassium sorbate, sodium benzoate and 4-hexylresorcinol alone and in combinations when applied on MPP stored at 5 °C. They concluded that 4-hexylresorcinol is more effective in combination with citric acid than when it was applied as a separate agent. Phosphates, polysaccharides andethylenediaminetetraacetic acid (EDTA) commonly have been combined with other substancesand used as ABA (Bobo-García et al., 2020).

Natural extracts are also effective in preventing browning. Some of these substances are green tea extract, garlic extract, *Capsicum* sp. (chili pepper) extract, *Citrus* sp. (lemon) extract, *Beta vulgaris* (Red beet) extract, heated onion extract, mate extract, rosemary and onion esential oils, and rice bran. Extract obtained from pineapple rind is effective on potato puree. Phenolic acids such as benzoic acid, amino acids (glycine, valine, methionine,phenylalanine) and products of the Maillard's reactions can also be effective ABA (Bobo- García et al., 2020) same as γ-aminobutyric acid (Gao et al., 2018),Chinese plant extract *Portulaca oleracea* L. (Liu et al., 2019) and cod skin peptides (Liu et al., 2018).

2.3. Packaging

The successful preservation of the quality and safety of MPP is influenced by the packaging material and the composition of the atmosphere inside the package. The composition of the packaging material as well as the packaging atmosphere affect the maintenance of low O_2 levels in the package, which inhibits the enzymatic browning reaction (Bobo-García et al., 2020). MPP is most often packaged in polymeric packaging materials such as polyamide (PA), polyethylene (PE) (Laurila et al., 1998; Rocha et al., 2003; Ierna et al., 2016), ethylene/vinyl acetate (EVAC), low density polyethylene (LDPE), polystyrene (PS), oriented polypropylene (OPP) and cellulose acetate (Gorris and Peppelenbos, 1992). These polymeric materials are most often combined in multilayer polymer packaging in order to make better use of and complement their properties. (Ahvenainen, 1996). The impact of the packaging material is significant on the shelf-life of the packaged product. Shakouri et al. (2014) investigated the impact of the transparent biaxially oriented polypropylene (BOPP) laminate; semitransparent BOPP; polyamide/polyethylene (PA/PE) laminate on the quality of microwave-dried potato cubes that have been blanched or steamed and packaged in vacuum, N_2 and natural atmosphere. Samples packed in PA/PE laminate and in vacuum were best preserved and there was minimal loss of ascorbic acid and minimal shrinkage of the sample. Hai-yuan et al. (2009) have peeled and sliced potatoes, treated them with 1% citric acid solution and placed them in plastic trays covered with PE, polyvinylidene chloride (PVDC) and polyethylene-polypropylene (PE/PP) film. Samples were then stored at 5 °C for 8 days. They concluded that PE/PP packaging can best preserve product quality. Lim et al. (2005) packaged the MPP samples in LDPE, PP, anti-fogging film and perforated film and concluded that the samples packaged in PP with 10% CO_2 and 5% O_2 showed the lowest weight loss and the lowest browning during storage.

The composition of the atmosphere inside the package depends on the permeability of packaging material, respiration of the potatoes and packaging type. At 2 ºC, unprocessed potatoes have a respiration rate of 1.22 mL CO_2 $kg^{-1}h^{-1}$, while peeled and sliced potatoes 2.55 to 6.1 mL CO_2 $kg^{-1}h^{-1}$ (Rocculi et al., 2009). Higher respiration rate contributes to faster product spoilage. After packaging, during respiration potatoes consume O_2 from the atmosphere in which they are packaged and produce CO_2 (Figure 8) and H_2O (Beltrán et al., 2005). Hence, it is important that the packaging is permeable to exchange gases (O_2 entry and

CO_2 exit) from the package until the composition of the gases in the package becomes optimal and steady state (Figure 9) is reached. If MPP is packaged in material that is poorly permeable to gas exchange, there is a risk of creating anaerobic conditions due to O_2 consumption and CO_2 accumulation and the development of unpleasant odors and food spoilage (Gorris and Peppelenbos, 1992). Since insufficient permeability of packaging is a common problem in the food industry, for the specific food products, perforations (Ščetar et al., 2010) or micro-holes are applied on packaging materials (Ahvenainen, 1996). Furthermore, the packaging should be permeable to water vapor due to transpiration of potatoes and the accumulation of moisture during changes in storage temperature, which favors the development of microorganisms that cause spoilage. Packaging must also ensure optimal ethylene permeability (Gorris and Peppelenbos, 1992).

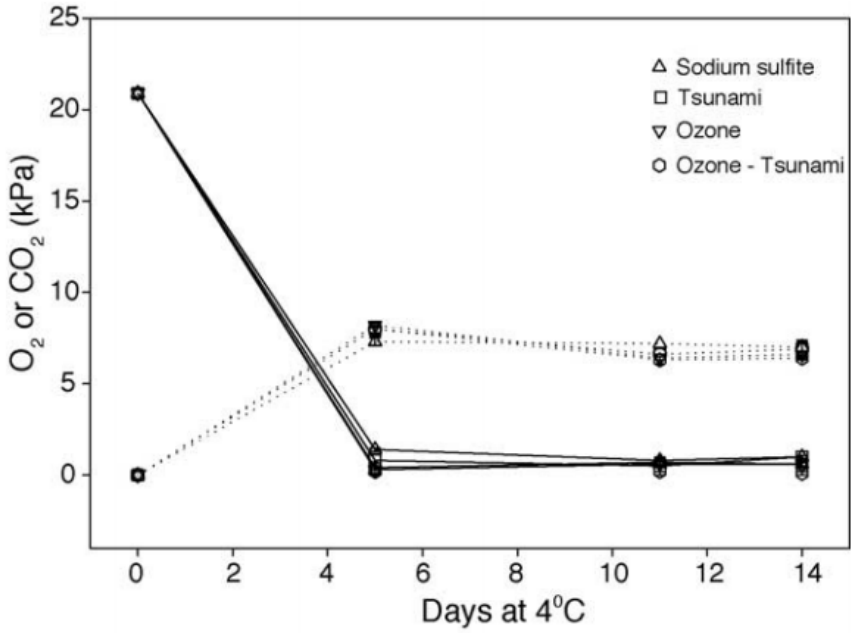

Figure 8. O_2 (_____) and CO_2 (……..) level during 14 days of storage of minimally processed Monalisa potatoes at 4 °C in low-density polyethylene film (Beltrán et al., 2005)

The most common packaging method in the production of MPFV is passive and active MAP as well as vacuum packaging (VP). The composition of gases in passive MA depends on the respiration of the product itself and the permeability of the material in which the product is packaged. Active modification of the atmosphere is achieved by evacuating the existing air from the packaging with a vacuum and replacing it with the desired gas composition or by adding substances that bind O_2, CO_2, ethylene or water vapor (Vujković et al., 2007). For fruits and vegetables storage, the optimal proportion of O_2 and CO_2 in the

package is 3-5%, while the proportion of nitrogen is 85-95% (Ahvenainen, 1996; Vujković et al., 2007). Cacacae et al. (2002) noted that MA (0.5% O_2, 95.5% N_2) in combination with ABA can preserve product quality.

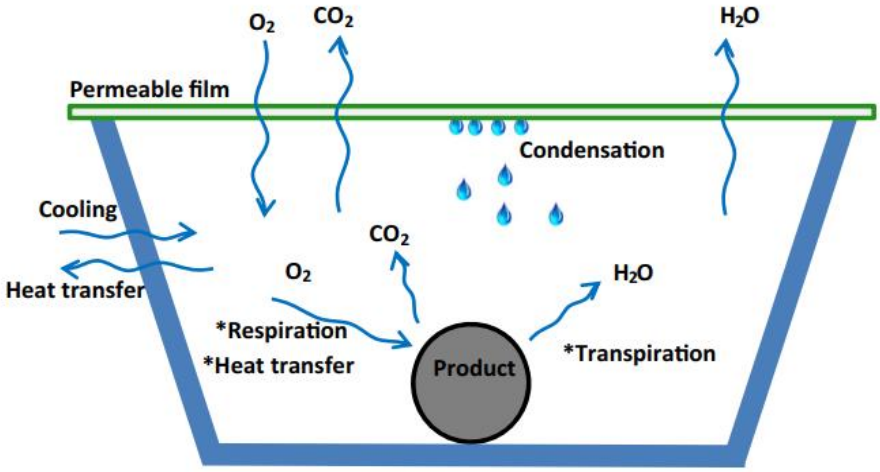

Figure 9. Scheme of gas exchange during the application of packaging in a modified atmosphere (Belay et al., 2016).

In the case of VP, all air is evacuated from the package and then the package is filled with the product and sealed inside the vacuum chamber. Air can also be evacuated by vacuum nozzles after the packaging is formed and the product is filled but before the packaging is sealed (Vujković et al., 2007). In the case of VP, it is necessary to choose an optimal material to avoid the accumulation of CO_2 during respiration of potatoes and creation anaerobic conditions which lead to undesirable odors, food spoilage and growth of pathogen bacteria such as *Clostridium botulinum*. To prevent this, the O_2 content of the package should not fall below 1% (Farber et al., 2003). Moderate (partial) VP is condition in which the product in the packaging is surrounded by air, but under low partial pressure (10 – 100 mBar) which slows down the respiration of the packaged product and the growth of microorganisms (Gorris and Peppelenbos, 1992; Embleni, 2013).

Montouto-Graña et al. (2012) observed that customers prefer to buy potatoes packaged in vacuum (cv. Kennebec) over potatoes packaged in MA (100% N_2). Rocha et al. (2003) reported that the vacuum-packaged Desiré potatoes were successfully preserved for one week. Beltrán et al. (2005) concluded that vacuum-packaged potato samples were better preserved from microbiological spoilage and retained the appropriate texture and aroma than samples in MAP. Pineli et al. (2005) also investigated the impact of MAP (10% CO_2, 2% O_2, 88% N_2

and 5% CO_2, 5% O_2, 90% N_2) and partial vacuum on the durability and quality of MPP and concluded that samples packaged in partial vacuum were better preserved than in the MAP. Samples packaged in MAP browned faster and they became harder as they dehydrated more. Also, their total soluble matter increased and their acidity decreased. MPP packaged inVP or MAP have a shelf-life of 5-7 days if they are stored at temperature of 4-5 °C (Rocha et al., 2003; Ierna et al., 2016).

Edible coatings and films that are coated over the product have been intensively researched and developed. Edible coatings most commonly consist of protein, carbohydrates (starch and starch derivatives, cellulose derivatives such as carboxymethyl cellulose, chitosan, pectin, alginate, etc.) and lipids (Ščetar et al., 2010). They are able to reduce moisture loss, O_2 supply, slow down respiration and ethylene production, and maintain the presence of volatile aromas (Ahvenainen, 1996). It is possible to incorporate substances that have antimicrobial properties such as organic acids, fatty acid esters, polypeptides, vegetable oils, nitrites, sulfites and biological active substances in form of e.g. phenolic plant extracts into the composition of edible coatings and films (Ahvenainen, 1996; Ščetar et al., 2010, Kurek et al., 2021).

3. Influence of thermal treatment on physical, chemical and sensory properties of minimally processed potato

Potatoes should be cooked (i.e. boiled, steamed, fried or baked) before consumption in order to certain individual components become easier to digest. Thus, properly applied high temperature, leads to the desirable physical, chemical and sensory changes in potato.

During cooking, undesirable microorganisms and anti-nutritional factors are eliminated, and certain compounds are created that contribute to the sensory properties like flavor, taste and color of cooked food as well as texture, such as crispiness and softness. Besides desirable characteristics, cooking has also some negative impacts on the food. During cooking, some nutrients are partially lost and, in some cases, mutagenic and potentially carcinogenic compounds could be formed.

Mutagenic compounds which belong to the group of PAHs partialy could derived from raw potato but also high temeperature of cooking could increase its presence in e.g. fried potato. Further, during frying acrylamide, potentially carcinogenic compond to humans, as by-products of Maillard's reactions, could be formed (Bansal and Kim, 2015; Gökman, 2016; Tian et al., 2016).

Texture is one of the most important sensory characteristics of any food. During heat treatment of MPP, the texture changes are affected by the properties such as dry matter content, specific gravity, amylose, sugars, protein, and nitrogen content in tubers. In order to be able to assess well which potatoes are suitable for cooking and which for frying, it is important to pay attention to properties such as tubers mealiness and waxyness (Jansky, 2010).

Mealiness is associated with high dry matter content and such potatoes are dry and granular. In addition to the high proportion of dry matter, the size and structure of starch grains also contribute to the mealiness. During cooking, starch gelatinizes, which creates pressure on the cell walls of potatoes, as a result of which they expand and burst. Cells in which gelatinized starch has been retained contribute to mealiness structure. Cells that burst and absorb water contribute to the development of waxyness. When chewing, the bound water is released and therefore the waxy texture contributes to the feeling of moisture in the mouth. On the other hand, gelatinized starch retains water which contribute the feeling of dryness in the mouth during chewing. Potatoes, which have larger cells and contain more starch, most often exhibit mealiness structure. In addition to the above, mealiness can also contribute to the thicker cell walls and middle lamellae, stronger pectic substances and cell cohesiveness and adhesiveness. Foods like chips need to have a crispy texture. Gelatinization and dehydration of starch during heating and softening of middle lamella contribute to crunchiness. Crunchiness is also affected by non-starch polysaccharides, lignin and proteins (Jansky, 2010).

Texture changes are also influenced by enzymatic and non-enzymatic degradation of pectin. During heat treatment, at temperature of 50-80 °C, pectin methyl esterase is activated and catalyzes the decomposition of pectin into demethylated pectin chains, which contributes to the softening of the texture. In addition to pectin methyl esterase, polygalacturonase also contributes to the disintegration of the cell walls and pectin (García-Segovia et al., 2008).

Cooking can affect color change in food, especially during frying and baking (Dourado et al., 2019). During processing of potatoes, the content of sugars decreases. As a result of boiling, the cell walls disintegrate and sugars are more easily extracted and dissolved in the water in which the potatoes are boiled (Pedreschi et al., 2009; Zhang et al., 2018). During frying and baking, the content of sugars decreases due to interaction of sugars with amino acids and compounds that cause dark color and specific odor and taste of fried or baked potatoes are formed (Halford et al., 2011; Dourado et al.,2019).

The aroma of potatoes develops only when potatoes are disintegrated (peeled, cut) or cooked. Due to lipid degradation, degradation of sugars, and Maillard's reactions, aroma-forming compounds develop during heat treatment of potatoes (Duckham et al., 2001; Oruna-Concha et al., 2001). Volatile, semi-volatile or non-volatile substances are responsible for the aroma of cooked potatoes, while the taste of cooked potatoes is defined by non-volatile substances (Bough et al., 2020).

During boiling of potatoes, there is no loss of water and the food is quickly heated evenly, but the tubers temperature never exceeds 100 °C (Jansky, 2010). Ribonucleotides contribute the most to the taste of boiled potatoes. Ribonucleotides are flavor enhancers and are responsible for umami flavor in food. In the initial boiling phase, at 50 °C, nucleases are activated that decompose ribonucleic acid (RNA) molecules and increase the concentration of 5′ribonucleotides such as inosine 5′monophosphate and guanosine monophosphate (GMP). 5′ ribonucleotides interact with amino acids such as glutamate and thus create the taste of boiled potatoes. Sugars in the form of glutamate glycoconjugates and potassium salts also contribute to the taste of umami (Jansky, 2010).

According to Bough et al. (2020) the most important components of the aroma of boiled potatoes are aldehydes and ketones from lipid degradation, pyrazines from Maillard's reactions, aldehydes from Strecker amino acid degradation and metabolite products of sugars degradation reactions. The products of lipid degradation are more numerous in boiled than in fried potatoes and are formed as a result of enzymatic reaction catalyzed by lipoxygenase. Degradation of fatty acids produces aldehydes and ketones that contribute to the development of fatty, fruity and floral notes (Duckham et al., 2002). The product of lipid oxidation c4-heptanal contributes to the development of earthy aroma. Other compounds that contribute to the development of aroma are methional, a compound formed in Strecker degradation reactions and methyoxypyrazines, which are also present in raw potatoes, etc. (Jansky, 2010).

During frying or baking, by Maillard's reactions which involve sugars, amino acids, RNA, and lipids, flavoring products are formed. Sugars such as glucose, fructose and sucrose give sweetness to potatoes which is desirable during the consumption of baked potatoes. Frying oil also contributes to the specific taste of fried or baked potatoes (Jansky, 2010).

During frying at high temperature, volatile compounds such as lipid degradation products, products of Maillard's reactions, sulfur compounds and methoxypyrazines (2–isobutyl-3-methoxypyrazine, 2-isopropyl-3-methoxypyrazine) as the most important component of the aroma of baked potatoes, are developed. Sugars and amino acids are also important for the development of the aroma of fried potatoes. The flavor of fried potatoes is

also affected by the oxidation products of the fatty acids in the frying oil. During baking, the potatoes are heated on the surface and water evaporates from the surface. Afterwards, the temperature from the surface spreads towards the inside of the potatoes and crispiness is created. The flavor of baked potatoes is also crated by contribution of β-damascenone, dimethyl trisulfide, decanal and 3-methylbutanal (Duckham et al., 2001; Oruna-Concha et al., 2001).

Heat treatment of potatoes also affects the nutritional composition and level of bioactive components in potatoes. During boiling, the concentration of minerals such as potassium, phosphorus and magnesium decreases, while during frying and baking their concentration remains almost unchanged. Iron and zinc concentrations also remain unchanged even during boiling most likely due to their firm binding to macromolecules in potatoes.

Further, during heat-treatment the concentration of water soluble and thermally unstable vitamin C expectedly decreases. Its reduction depends on the temperature and cooking time and it can vary from 10 to even 80% (Tian et al., 2016).

Contrary, during cooking (roasting, shallow frying, deep-fat frying) concentration of proteins is increased due to water evaporation and dry matter increase.The content of proteins in Latvian potatoes during different heat treatments increased from 1.55 ± 0.04 g 100 g^{-1} in raw potatoes to 2.46 ± 0.10, 2.61 ± 0.13 and 4.27 ± 0.08 g 100 g^{-1}in roasted, shallow-fried and deep-fat fried potatoes, respectively. Significant increases in aspartic acid, valine, methionine, isoleucine, tyrosine, phenylalanine, histidine, lysine and arginine concentration were also observed (Murniece et al., 2011). Also, during cooking, proteins denature and become easier to digest and the risk of causing allergies is reduced.

Although most scientific papers reported the decrease of carotenoids during heat treatment of potatoes, carotenoids can interact with proteins during cooking, what can contribute to its beter preservation (Tian et al., 2016).

In addition to proteins, the concentration of dietary fiber also increases during cooking. Murniece et al. (2011) found that after shallow frying (150 ± 5 °C), deep-fat frying (180 ± 5 °C) and roasting (210 ± 5 °C) the content of dietary fiber in all investigated potato cultivars increased significantly in comparison with the content of dietary fiber in raw potato (0.56-0.82 g 100g^{-1} FW).

The concentration of phenolic compounds also changes during cooking. According to Faller and Fialho (2009) the content of phenolics in peeled tubers after boiling, steaming and microwaving increased by 81.4, 22.8 and 80.81%, respectively. Blessington et al. (2010) found that the content of phenolics increased for 36.36, 46.12, and 47.48% after baking,

frying and microwaving, respectively. The increase in phenolics content occurs due to rupture of cell walls and break of the bonds between the bound phenolics and dietary fiber, which allows better extraction of phenolics from the cell matrix. Furthermore, PPO is inactivated during heat treatment and phenolics do not decrease due to oxidation and polymerization reactions (Tian et al., 2016). During frying and baking, dry matter content increases, which also affects the increase in phenolics content.

In contrast, Lemos et al. (2015) stated that the content of phenolics in raw potatoes were 209 mg GAE 100 g^{-1} (fresh weight), while in baked potatoes it was 38.1 mg GAE 100 g^{-1}, in boiled potatoes 137.6 mg GAE 100 g^{-1}, in microwaved potatoes 74.0 mg GAE 100 g^{-1} and in steamed potatoes 130.4 mg GAE 100 g^{-1}. The content of phenolics in heat-treated samples can decrease by solubility of phenolics in water and their degradation by increased temperature, or participation of phenolics in Maillad's reactions (Tian et al., 2016). Changes in the chemical composition of raw and heat-treated potatoes are shown in Table 2.

Table 2. Chemical composition of raw and cooked potato (g 100 g^{-1}) (Vreugdenhil, 2007)

	Dry matter	Protein	Starch	Sugars	Fat	Dietary fibre
Uncooked[a] (flesh only)	21.0	2.1	16.6	0.6	0.2	1.3
Boiled (flesh only)	19.7	1.8	16.3	0.7	0.1	1.2
Baked (without skin)	21.1	2.2	17.3	0.7	0.1	1.4
Roast (in corn oil)	35.3	2.9	25.3	0.6	4.5	1.8
Chipped (in blended oil)	46.5	3.9	29.5	0.6	6.7	2.2

[a] Four varieties sampled over 2 years.

During frying and baking of potato, undesirable, potentially carcinogenic compounds such as acrylamide and PAHs are formed. Although the chemical route of acrylamide formation has not yet been fully elucidated, it is known that it is a compound formed as the product of interaction of reducing sugars (glucose and fructose) and amino acid asparagine in Maillard's reactions during frying or roasting of potatoes at temperature above 120 °C (Figure 10) (Medeiros Vinci et al., 2012). Based on animal research, the International Agency for Research on Tumors has classified acrylamide into group 2A (possibly carcinogenic to humans) (Gökman, 2016). Namely, it was discovered that the intake of acrylamide in animals produces carcinogenic, genotoxic and neurotoxic metabolites such as glycidamide, which has an adverse effect on animal reproduction (EFSA, 2015; Badanjak Sabolović and Rimac

Brnčić, 2016). According to EC (2017), the reference value of acrylamide content in fried potatoes is 750 μg kg^{-1}. The acrylamide content can be reduced by the use of potato cultivars with lower content of sugars (glucose, fructose) and asparagine, as well as by the use of tubers that are not bruised and damaged (EC, 2017). Amrein et al. (2003) stated cv. Lady Claire, Lady Rosetta, Hermes, Markies, Marlene, Panda, Saturn, Erntestolz as the cultivars with reduced content of sugars. In addition to the cultivar's selection, the proportion of acrylamide can be influenced by the use of good agrotechnical and storage measures (storage temperature above 6 °C, control of relative humidity and use of anti-sprouting agents) (EC, 2017). Acrylamide content is also affected by peeling of potatoes, thickness of slices, treatment of slices with asparaginase enzyme, immersion of potato slices in salt solution (NaCl), treatment with antioxidants (green tea extract, oregano and cinnamon) and amino acids (e.g. glycine) (Sabolović and Rimac Brnčić, 2016; FoodDrink Europe, 2019). Also, several researches confirm that phenolics contribute to reduced levels of acrylamide in fried potatoes (Zhu et al., 2010; Kalita et al., 2013).

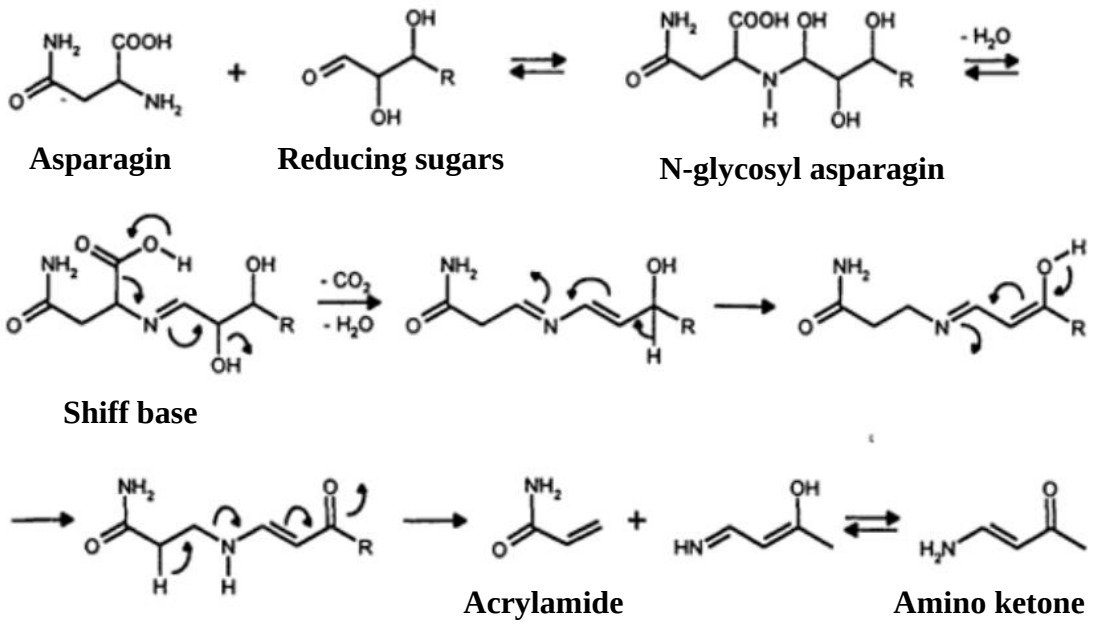

Figure 10. Hypothesis of the formation of acrylamide from asparagine in the presence of reducing sugars (Blank et al., 2005)

PAHs are a group of contaminants that are absorbed into food from the environment (soil, air and water) (Figure 11) or formed during thermal processing of food due to incomplete combustion of organic matter (Bansal and Kim, 2015; Singh et al., 2016). In their chemical structure, they possess 2 or more organic rings composed of carbon and hydrogen. Compounds having 2-4 rings are classified as light fractions while compounds containing more than 4 rings are classified as heavy fractions (Singh et al., 2016). The light fractions of

PAHs cause systemic toxic effects, while heavy fractions of PAHs are genotoxic and mutagenic (Hanedar et al., 2014). The accumulation of PAHs in fried potatoes is influenced by raw material (cultivar properties, growth conditions and post-harvest processing), frying oil and frying itself (Samsøe-Petersen et al., 2002; Wennrich et al., 2002; Zhong and Wang, 2002; Abou-Arab et al., 2014). According to EC (2011), the maximum permitted amount of benzo(a)pyrene for human consumption is 2 µg kg^{-1}in oils. The level of PAH4 group (benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene and chrysene) should be below 10 µg kg^{-1}.

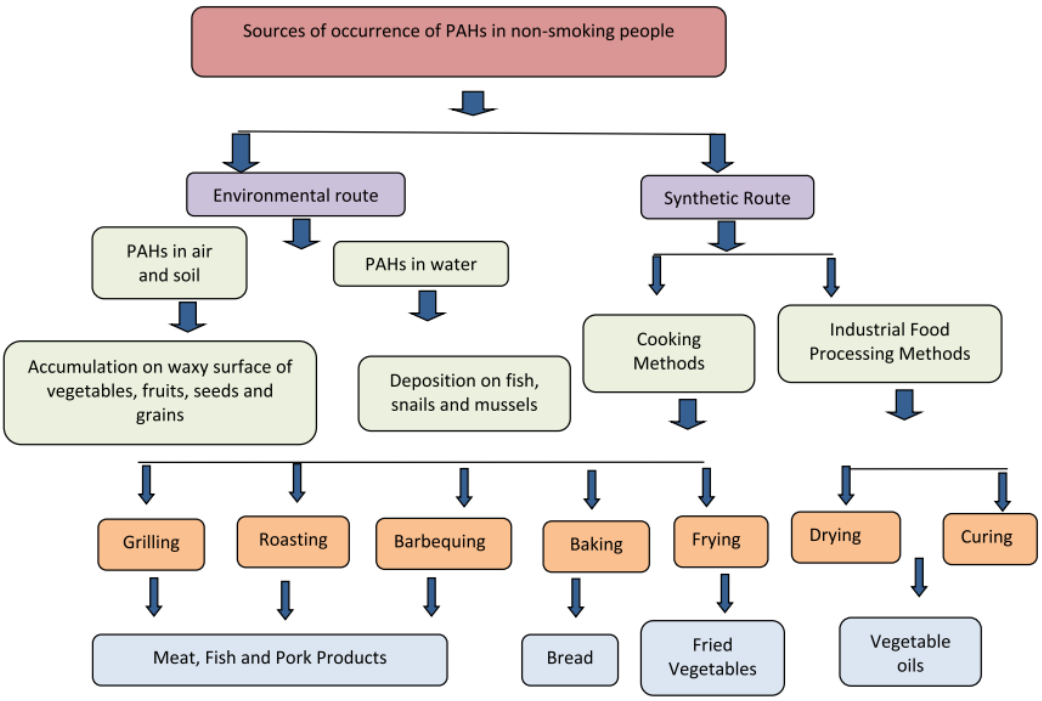

Figure 11. The source of PAHs contamination in food (Bansal and Kim, 2015)

4. Hypothesis, research objectives, and expected scientific contributions

The research started with the hypothesis that industrial potato cultivars will be more suitable and stable for the production of MPP than table cultivars. Also, it was assumed that potato treatment with anti-browning solutions, packaging in vacuum or MA and

storage of MPP at lower temperature will have a positive effect on physical, chemical and sensory properties of MPP, while tubers aging and storage time of MPP will have a negative impact to the above characteristics. It was also supposed that tubers aging and storage time of MPP will increase the content of sugars, acrylamide and PAHs after heat treatment of the samples.

One of the objectives of the Ph.D. thesis is to gain knowledge about the chemical composition of different potato cultivars and its changes during storage as well as how to prevent enzymatic browning of sliced potatoes depending on the used ABA and applied packaging atmosphere. Moreover, the aim of the study was to gain knowledge about the maintaining the desired chemical composition of potatoes in order to reduce the content of acrylamide and PAHs in fried and baked potatoes and to optimize the processing and storage conditions of MPP.

The research plan was divided into three parts:

In the first part of the research, the influence of selected cultivars, ABA, packaging atmosphere, temperature and MPP storage time on the quality and sensory of raw and boiled samples was examined (***Publication No.1***).

The second part of the study examined the influence of cultivar, tubers aging, ABA, packaging atmosphere, temperature and MPP storage time on the quality and sensory properties of raw MPP as well as subsequently boiled, fried and baked samples (***Publication No. 2***).

The third part of the research examined the changes of chemical constitutients of potato.Changes in content of phenolics, glucose, fructose, sucrose and acrylamide (only in fried) in potatoes influenced by cultivar, tubers aging, MPP storage time, boiling and frying were examined (***Publication No. 3)***. Additionally, changes in PAHs levels influenced by cultivar, MPP storage time and frying were also examined ***(Publication No. 4).***

Throughout this dissertation the following issues were examined:

1) The influence of 10 days storage at 3 and 10 °C on quality, safety and sensory properties of MPP (raw and subsequently boiled in distilled water at 100°C for 15 min) produced from two selected cultivars (cv. Birgit and Lady Claire), treated by two ABAs (SC, 1% or SA, 2%), and packaged in VP or MAP (10% CO_2, 3% O_2, 87% N_2) (***Publication No. 1***).

2) The influence of tubers aging of selected cultivars on the quality and sensory properties of MPP (raw and subsequently boiled in distilled water at 100°C for 15 min, fried in sunflower oil at 180°C for 5 min and baked in an oven at 220°C for 30 min) during 8 days storage at 10 °C where MPP is produced by ABA treatment and packaged in VP and MAP (10.0% CO_2, 3.0% O_2, 87.0% N_2) (***Publication No. 2***)

3) Chemical composition (content of phenolics, glucose, fructose, sucrose and acrylamide in slices fried in sunflower oil at 180°C for 5 min) of MPP in the dependence of tubers aging of cv. Birgit and Lady Claire, storage time and subsequently applied cooking (boiling in distilled water at 100°C for 15 min and frying in sunflower oil at 180°C for 5 min) (***Publication No. 3)***

4) PAH content in fried MPP slices (fried in sunflower oil at 180°C for 5 min) in the dependence of cultivars, ABA treatment and packaging (VP and MAP) during 8 days storage of MPP at 10 °C (***Publication No. 4***)

Throughout this dissertation following achievements were obtained:

1) knowledge of the influence of ABA, packaging atmosphere and storage conditions on the shelf-life of MPP as well as knowledge of the influence of the listed parameters on the content of acrylamide and PAHs in fried potatoes

2) knowledge of the chemical composition that occur in raw potatoes during storage and in MPP during processing, storage and preparation for consumption

3) knowledge of the optimal conditions for the production and storage of MPP in order to achieve the required quality and shelf-life

4) update of the MPP production topic, which has so far been completely neglected in Croatia from scientific point of view

5) contribution to better knowledge of potato cultivars which grow in Croatia and are present on Croatian market

Chapter 2

Publication No. 1: Effect of Anti-Browning Agents and Package Atmosphere on the Quality and Sensory of Fresh-Cut Birgit and Lady Claire Potato during Storage at Different Temperatures

Journal of Food Processing and Preservation

Dite Hunjek, D., Repajić, M., Ščetar, M., Karlović, S., Vahčić, N., Ježek, D., Galić, K., Levaj, B. (2020) Effect of Anti-Browning Agents and Package Atmosphere on the Quality and Sensory of Fresh-Cut Birgit and Lady Claire Potato during Storage at Different Temperatures. *J. Food Process. Preserv*. **44,** 1-15.doi:10.1111/JFPP.14391

Author contributions (Contributor Roles Taxonomy -CRediT)

Draženka Dite Hunjek-conducting an experiment, data analysis, drafting the manuscript
Maja Repajić-contribution during statistical analysis and interpretation of the data, revising the manuscript
Mario Ščetar-participation in one part (packaging) of the analysis
Sven Karlović - interpretation of texture results
Nada Vahčić-contribution during statistical analysis
Damir Ježek-revising the manuscript
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ORIGINAL ARTICLE

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Effect of anti-browning agents and package atmosphere on the quality and sensory of fresh-cut Birgit and Lady Claire potato during storage at different temperatures

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Abstract

The influence of cultivar, anti-browning agents, package atmosphere, storage time and temperature on quality, and sensory of fresh-cut potatoes (FCP) were investigated. Slices of cv. Birgit and Lady Claire were dipped in water, sodium chloride solution (1%) and sodium ascorbate solution (2%) and stored under air, vacuum, and active modified atmosphere at 3 and 10°C for 10 days. Dry matter, pH, color and texture properties, gas composition within packages, and microbial activity were monitored during storage. Also, raw and boiled FCP were sensory evaluated. Examined influences significantly affected majority of FCP properties. Generally, sodium ascorbate showed more efficiency in browning prevention, as well as vacuum-packaged samples were more acceptable. Storage at 3°C did not have significantly better effect compared to storage at 10°C. FCP quality and sensory retained well till the 8th day of storage. Cv. Birgit demonstrated greater potential for FCP production.

Practical applications

Although fresh-cut potato (FCP) has been extensively investigated, there is an existing need for further study of adequate cultivars, as well as prevention of enzymatic browning as important factor for maintaining its quality. This research provides a better insight of the influence of legally permitted anti-browning agents (*quantum satis*) that are accepted by consumers as natural and nontoxic food additives, as well as low-cost packaging method and storage conditions on FCP quality and sensory properties in order to achieve and improve its required quality and durability during storage. Furthermore, present study could also contribute to better knowledge of relatively new potato cultivars on the market.

1 | INTRODUCTION

Potato (*Solanum tuberosum*) is widely spread vegetable, often used in human diet (Furrer, Chegeni, & Ferruzzi, 2017), suitable for storage as unprocessed up to 1 year. According to Wang et al. (2015), production of fresh-cut potato (FCP) has become more popular in the last decades, since the preparation of potato dishes requires activities such as peeling and cutting, which are less appropriate in nowadays lifestyle, where less time should be taken for meals preparation in the households and restaurants. Accordingly, Jabs and Devine (2006) stated that in the USA overall time spent on meal preparation has decreased for 38.6% between year 1965 and 1995/1998, and approximately 64% and 35% of males and females, respectively, aged 21–64 years, reported no time spent in daily food preparation.

As reported by The International Fresh-Cut Produce Association, fresh-cut fruit and vegetables are defined as fruit and vegetables physically altered, but still fresh or cleansed and 100% usable packaged, very convenient and withheld nutritional value, as well as with unchanged taste and retained freshness (International Fresh-cut Produce Association, 1999). Despite its convenience, such products are very perishable and susceptible to browning and thus consequently have high demands for its production and storage, as well as have short shelf life (usually 7 days) (Laurila, Hurme, & Ahvenainen, 1998; Rocculi, Romani, Galindo, & Rosa, 2009). Therefore, among other important tasks in the FCP production, prevention of negative color changes is obligatory, as well as health safety insurance.

Undesirable browning is a result of potato chemical composition and enzyme activity. The browning that occurs on FCP is a consequence of the enzymatic browning that comes with potato cutting when enzymes are activated during oxygen exposure, where phenolic compounds are transformed into quinone and further melanoid pigments are formed (Whitaker & Lee, 1995), which are brownly colored. Potato browning in FCP production is endeavored with several approaches, such as treatment with anti-browning agents (ABA), appropriate packaging (package atmosphere, packaging material), and storage temperature. In addition, it is necessary to use potato cultivars that are not prone to browning and that way prolong FCP shelf life. Susceptibility to browning of many cultivars was investigated in several research, where following cultivars arranged by the sequence of browning susceptibility: Monalisa > Spunta > Liseta > C ara>Agria (Cantos, Tudela, Gil, & Espiän, 2002) and Marabel > Agat a > Agria > Vivaldi > Almera (Cabezas-Serrano, Amodio, Cornacchia, Rinaldi, & Colelli, 2009).

Besides cultivar, ABA could be helpful for browning decrease. Numerous studies were conducted to find the optimal agent for potato browning prevention along with maintaining its safety and acceptable sensory properties during storage time, for example, L-cysteine, citric and ascorbic acid (Li et al., 2017; Rocculi et al., 2007), NatureSeal, sodium acid sulfate (Calder, Kash, Davis-Dentici, & Bushway, 2011), and γ-aminobutyric acid (Gao, Zeng, Ren, Li, & Xu, 2018). Searching for more natural and nutritional ABA, Liu et al. (2019) investigated Chinese plant (*Portulaca oleracea* L.) extract and Liu et al. (2018) carried out study upon peptides from cod skin. Effectiveness of ABA also depends on cultivar and package atmosphere.

Package atmosphere prolongs expiration date due to its effect on the respiration rate decrease. It can be modified passively or actively. For active modified atmosphere packaging (MA) it is important to apply an optimal ratio of oxygen, nitrogen, and carbon dioxide (Gunes & Lee, 1997). For example, Cacace, Delaquis, and Mazza (2002) documented that MA (0.5% O_2, 95.5% N_2) in combination with N-acetyl-L-cysteine, diethylenetriamine pentaacetic acid, erythorbic acid, and especially citric acid keep quality of FCP cv. Russet Burbank, while Montouto-Graña, Cabanas-Arias, Porto-Fojo, Vazquez-Oderiz, and Romero-Rodriguez (2012) reported that consumers preference was given more to vacuum packaged potatoes cv. Kennebec than ones packaged in MA (100% N_2). Furthermore, according to Rocha, Coulon, and Morais (2003), the shelf life of cv. Desire stored in vacuum was effectively extended to nearly 1 week and Beltran, Selma, Tudela, and Gil (2005) reported that ozone and Tsunami solutions for cv. Monalisa packaged in vacuum were the most effective for microbial growth prevention and retention of its strips initial texture and aroma.

In addition, quality of FCP is strongly affected by storage temperature, where lower temperatures are preferred (Cabezas-Serrano et al., 2009), as they contribute to product shelf-life extension due to reduction of respiration rate (Ghazavi & Houshmand, 2010) and various deterioration processes.

In order to achieve high quality FCP with satisfying sensory characteristics and shelf life, it is necessary to continuously conduct studies, which will include new cultivars and their interaction with ABA, packaging and storage conditions, as well the establishment of their optimal parameters. There are many studies related to FCP shelf life prolonging of many cultivars, but there is a lack of investigations which include cv. Birgit and Lady Claire. These cultivars arouse interest, since cv. Birgit is described in European Cultivated Potato database (2017) as less susceptible to browning, and cv. Lady Claire is an industrial cultivar mainly intended for chips processing, where browning is also undesirable. As well, previous results reported that ABA sodium chloride and sodium ascorbate showed good efficiency on the apples (Li, Wills, & Golding, 2015), but to our knowledge, there are no reports about their application on the potato. Sodium chloride, being natural, available and inexpensive ABA commonly present in potato dish, inactivates enzyme polyphenol oxidase (Marshall, Kim, & Wei, 2000). Sodium ascorbate, which represent form of vitamin C naturally occurring in potato as ascorbic acid (Tudela, Espin, & Gil, 2002), is permitted food additive (European Regulation (EC) No 1333/2008, 1129/2011). It acts on several ways, for example, as reducing agent reacts with quinone by reducing it back to phenols, as chelating agent causes enzyme activity decrease, and as an oxygen scavenger for the removal of molecular oxygen in polyphenol oxidase reactions (Marshall et al., 2000).

Hence, the aim of this study was to investigate the influence of sodium chloride (1%) and sodium ascorbate (2%) solutions on quality and sensory properties of cv. Birgit and Lady Claire FCP packaged in vacuum and MA (10.0% CO_2, 3.0% O_2, and 87.0% N_2) and stored at 3 and 10°C during 10 days.

2 | MATERIAL AND METHODS

2.1 | Raw materials

Potato tubers (*Solanum tuberosum L.*) of two different cultivars, Lady Claire and Birgit, were used. Lady Claire is a Dutch industrial potato cultivar, while Birgit is German table potato. Both cultivars have been cultivated for many years in Croatia. The potatoes were grown during 2015 and harvested in Slavonia region (Croatia) (45°40′N, 17°1′E). After harvesting, potatoes were treated with anti-sprouting agent (Gro Stop Basis and Gro Stop Fog, Certis Europe B.V., United

Kingdom), placed in wooden pallet boxes and stored for 8 months in dark room at 8°C with approximately 100% RH. Before the transportation to the laboratory in net (raschel, leno) bags, potatoes were stored at 16°C for 3 days.

2.2 | Treatment with anti-browning agents

For analysis purpose, undamaged and uniform tubers with diameter greater than 35 mm were selected. Potatoes were manually peeled with knife and tap water washed, cut into 4 mm slices with a commercial cutting machine (MCM62020-CNCM30, Multitalent, Bosch, Slovenia) and dipped in distilled water (control), sodium chloride solution (1%, w/v) (Solana d.d. Tuzla, Bosnia and Herzegovina), and sodium ascorbate solution (2%, w/v) (Nutrimedica d.o.o., Zagreb, Croatia) for 3 min at 18°C. The sample/solution (g/mL) ratio was 1:4. To reduce free water on potato, slices were put on a drain board. Only uniform slices without broken pieces were used for further experiment.

2.3 | Packaging of potato slices and storage conditions

After anti-browning treatment, samples were packaged (300 g) in polyethylene (PE) (45 μm) and pouches made of bi-layer laminates of polyamide/polyethylene (PA/PE): ribbed layer PA 30 μm/PE 70 μm, and flat layer PA 30 μm/PE 100 μm. PE bags were used for air packaged samples (control) and PA/PE bags were used for vacuum and MA packaging (10.0% CO_2, 3.0% O_2, and 87.0% N_2) (Messer Croatia Plin d.o.o., Croatia). For air and vacuum packaged samples, a WS110W vacuum packager (Gorenje, Slovenia) and for MA packaging Junior Digit device (Besser Vacuum, Italy) were used. Prepared samples were stored in refrigerator (Beko, Istanbul, Turkey) at 3 and 10°C. All samples (n = 36) were analyzed on the 0, 2nd, 4th, 8th, and 10th day of storage.

2.4 | Determination of dry matter content and pH value

Potato slices were homogenized with kitchen blender (CNHR9EV, Bosch, Slovenia) and obtained pure was used for dry matter determination by drying in oven at 103 ± 2°C to constant mass (AOAC, 1990) The determination of pH value was conducted using pH meter (SevenEasy pH Meter S20, Mettler Toledo, Switzerland). All measurements were triple performed (n = 3).

2.5 | Color analysis

For color analysis, three slices of each sample were measured by colorimeter (Spectrophotometer CM-3500d, Konica Minolta, Japan) using D65 light source with 2° angle observer and measuring plate with 30 mm diameter hole. Color parameters L^* [lightness, (0–100)], a^* [redness (+) to greenness (–)], and b^* [yellowness (+) to blueness (–)] were triple recorded for each slice (n = 9). Before each set of measurements, the device was calibrated with pure white (100% reflection) and black (0% reflection) standard, according to manufacturer's instructions. All measurements were conducted in Specular Component Excluded mode.

2.6 | Texture analysis

Texture analyzer (TA.HD.plus Texture Analyser, Stable Micro Systems, UK) was used for texture analysis, where three slices from each sample were tested in triplicate (n = 9) using 2 mm stainless-steel punch probe with 5 kg load cell. Speed before penetration (pre-test speed) was adjusted at 1 mm s^{-1} and speed during the analysis (test speed) was set to 0.5 mm s^{-1}. Textural parameters firmness (N), elasticity (mm), and work required for chewing (J) were calculated, where firmness was calculated as the maximum force achieved during probe penetration into the sample, elasticity was calculated as the distance which probe has passed from the beginning of the penetration to the breaking of the sample, and work required for chewing (presents energy needed for needle to break the sample) was calculated as area under force-distance curve.

2.7 | Monitoring the package gas composition

Gas (O_2 and CO_2) content (%) in the packages was measured in triplicate (n = 3) by O_2/CO_2 analyzer (Oxybaby V O2/CO2, Witt-Gasetechnik, Germany). Before each measurement, the instrument was calibrated with ambient air.

2.8 | Sensory analysis

For sensory evaluation, along with raw samples, boiled samples were prepared as follows: 100 g of each sample was boiled in 500 ml of boiled distilled water for 15 min and drained. After cooling at room temperature, samples of boiled potato, as well as raw samples, were served on plastic coded plates and sensory evaluated by trained panel of five people (n = 5) from the faculty staff and students using Quantitative Descriptive Analysis. Prior evaluation, panelists were trained in 2 hr session to assess basic information and define sensory attributes related to examined product. Raw samples were sensory analyzed for color (in terms of browning) with scores 5 = complete browning, 4 = average browning, 3 = light browning, 2 = no browning (yellow), and 1 = no browning (white or cream). Intensity of characteristic odor and off-odor were scored with 5 = very pronounced, 1 = absent odor/off-odor scale. Moistness and firmness were examined by pressing the slices between the thumb and point finger and evaluated with following scale: 5 = very firm and wet to 1 = very

soft and dry (Ierna, Pellegrino, Di Silvestro, & Buccheri, 2016). Along with the above properties, creaminess, characteristic taste, as well as sweet, sour, salty, bitter, and off-taste were evaluated in boiled samples (5 = very pronounced, 1 = absent).

2.9 | Microbiological analysis

Potatoes used for testing corresponded to the requirements of the European Regulation (EC) No. 396/2005 on the maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC and Commission Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs.

For microbial analysis, samples were taken from each package and analyzed by HRN EN ISO 4833:2008 for aerobic mesophilic bacteria and HRN ISO 21528-2:2008 for *Enterobacteriaceae* in two replicates ($n = 2$) and list of samples which did not meet limits of microbiological safety according to the legal regulations (Ministry of Agriculture, Fisheries and Rural Development of the Republic of Croatia, 2009) is shown.

2.10 | Statistical analysis

The statistical analysis was carried out using Statistica ver. 8.0 software (Statsoft Inc., Tulsa, USA). Experiments were designed as full factorial randomized experimental design (Tables 1–3). Descriptive statistics was used to assess the basic information about the experimental data set. Dependent continuous variables were: dry matter (%), pH value, L^*, a^*, b^*, firmness (N), elasticity (mm), work (J), content of O_2 (%) and CO_2 (%), and 17 sensory attributes. Independent categorical variables were: (a) potato cultivars (Birgit and Lady Claire), (b) storage temperature (3 and 10°C), (c) package atmosphere (air, vacuum, MA), (d) ABA [water, sodium chloride (1%), sodium ascorbate (2%)], and (e) storage time (0, 2nd, 4th, 8th, and 10th day). Continuous variables were analyzed by multivariate analysis of variance (MANOVA) and marginal mean values were compared with Tukey's LSD multiple comparison tests. To determine the relationships among continuous variables, Pearson's correlation coefficient was calculated. The significance level for all tests was $p \leq .05$. In addition, the Principal Component Analysis (PCA) was performed on the correlation matrix using the physical, chemical, and sensory analysis in order to examine any possible grouping of samples by applied conditions (cultivar type, ABA, package atmosphere, storage temperature, and storage time).

3 | RESULTS AND DISCUSSION

3.1 | Dry matter and pH value

All investigated influences significantly affected dry matter and pH value of examined samples ($p \leq .05$), except storage temperature on pH value, where significance was absent ($p \geq .05$) (Table 1). Grand mean of potatoes dry matter was 21.50% and for pH value it was 6.11. Obtained results for dry matter are in accordance with Cabezas-Serrano et al. (2009) study, where five cultivars (Marabel, Agata, Agria, Vivaldi, Almera) were investigated and dry matter values were in range from 16.5% to 22.3%, while Ierna et al. (2016) reported 16.7%–22.0% of dry matter in cv. Antea, Arinda, Ditta, Liseta Marabel, Matador, Mondial, and Spunta.

Cv. Lady Claire showed higher dry matter compared to cv. Birgit, what is in accordance with the data in the European Cultivated Potato Database (2017) where is stated that dry matter content in cv. Lady Claire is high and in cv. Birgit middle in comparison with other cultivars.

Regard to type of ABA, obtained results showed the highest dry matter content in samples treated with sodium chloride solution (21.97%), followed by sodium ascorbate (21.68%) and water (20.84%). Similar observation was reported by Jiang, Pen, and Li (2004), in which study fresh-cut Chinese water chestnut treated with citric acid had higher total dry matter compared to nontreated samples. Contrarily, Rocculi et al., (2007) proved that ABA (citric acid, ascorbic acid, and L-cysteine) increased metabolism of potato, which depends on ABA type (Rocculi et al., 2009), and could led to decrease of dry matter.

Dry matter content also varied depending on the package atmosphere, where samples packaged in air showed the lowest dry matter (21.11%), while other two atmosphere types were described with slightly higher dry matter contents (MA 21.80%, vacuum 21.58%). According to Rocha et al., (2003) vacuum potato packaging reduces the level of respiration and therefore less substrate is used for this process. In that way, such packaging does not cause decrease in potato dry matter. Similar explanation could also be applied to MA packaged samples due to lower O_2 availability.

As can be noticed, storage at lower temperature recorded slightly higher dry matter (21.65%) compared to higher storage temperature (21.34%), what could be due to metabolic process variations upon different temperatures (Ghazavi & Houshmand, 2010). At the same time, dry matter slightly decreased by the end of storage, from 21.39% to 21.00%. During potato storage, total dry matter decreases because tubers use starch for energy supply (Wustman & Struik, 2007). In Erturk and Picha (2007) research, the reduction of the dry matter content in fresh-cut sweet potato packaged in vacuum and stored at 2 and 8°C during 14 days was also observed, as well as in studies of Jiang et al., (2004) with fresh-cut Chinese water chestnut and Shah and Nath (2008) with minimally processed litchis.

Determined pH values of all samples were in 6.03–6.18 range with 6.11 established as grand mean. These results correspond to previous research, where Rocha et al. (2003) reported pH value 6.6 in cv. Desire and Tsouvaltzis, Deltsids, and Brecht (2011) documented 6.07 as pH value in cv. Russet Burbank. Samples of cv. Birgit were slightly more acid than cv. Lady Claire samples (Table 1), probably due to cultivar differences. Similarly, Ierna et al. (2016), who analyzed five cultivars (Antea, Arinda, Ditta, Liseta Marabel, Matador, Mondial, Spunta), determined pH values in range 6.0–6.8.

TABLE 1 Influence of cultivar, anti-browning agent, package atmosphere, storage temperature, and storage time on the physical and chemical parameters as well as gas composition of raw fresh-cut potato

Source of variation	Dry matter (%)	pH value	L^*	a^*	b^*	Firmness (N)	Elasticity (mm)	Work (J)	O_2 (%)	CO_2 (%)
Cultivar	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .61$	$p = .13$	$p = .53$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
B	20.72 ± 0.05^{a}	6.09 ± 0.00^{a}	72.87 ± 0.11^{b}	2.04 ± 0.04^{b}	39.68 ± 0.14^{b}	6.32 ± 0.05^{a}	1.19 ± 0.02^{a}	1.83 ± 15.04^{a}	9.82 ± 0.01^{a}	6.62 ± 0.07^{a}
LC	22.28 ± 0.05^{b}	6.13 ± 0.00^{b}	70.17 ± 0.11^{a}	0.28 ± 0.04^{a}	31.89 ± 0.14^{a}	6.35 ± 0.05^{a}	1.16 ± 0.02^{a}	1.84 ± 15.04^{a}	11.26 ± 0.01^{b}	7.49 ± 0.07^{b}
Anti-browning agent	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .08$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .23$	$p = .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
W	20.84 ± 0.06^{a}	6.09 ± 0.00^{a}	71.51 ± 0.13^{ab}	1.24 ± 0.05^{a}	34.19 ± 0.18^{a}	6.32 ± 0.06^{ab}	1.18 ± 0.02^{a}	1.83 ± 18.42^{ab}	10.84 ± 0.02^{b}	6.98 ± 0.09^{a}
SC (1%)	21.97 ± 0.06^{c}	6.13 ± 0.00^{b}	71.17 ± 0.13^{a}	1.15 ± 0.05^{a}	36.43 ± 0.18^{b}	6.51 ± 0.06^{b}	1.15 ± 0.02^{a}	1.88 ± 18.42^{b}	10.42 ± 0.02^{a}	7.44 ± 0.09^{b}
SA (2%)	21.68 ± 0.06^{b}	6.12 ± 0.00^{b}	71.88 ± 0.13^{b}	1.09 ± 0.05^{a}	36.74 ± 0.18^{b}	6.18 ± 0.06^{a}	1.20 ± 0.02^{a}	1.80 ± 18.42^{a}	10.37 ± 0.02^{a}	6.75 ± 0.09^{a}
Package atmosphere	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .14$	$p = .03^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
A	21.11 ± 0.06^{a}	6.10 ± 0.00^{a}	70.61 ± 0.13^{a}	1.48 ± 0.05^{c}	34.54 ± 0.18^{a}	6.54 ± 0.06^{b}	1.19 ± 0.02^{a}	1.88 ± 18.42^{b}	15.75 ± 0.02^{c}	2.77 ± 0.09^{a}
V	21.58 ± 0.06^{b}	6.10 ± 0.00^{a}	71.50 ± 0.13^{b}	0.82 ± 0.05^{a}	36.04 ± 0.18^{b}	6.26 ± 0.06^{a}	1.14 ± 0.02^{a}	1.83 ± 18.42^{ab}	14.93 ± 0.02^{b}	4.76 ± 0.09^{b}
MA	21.80 ± 0.06^{c}	6.13 ± 0.00^{b}	72.45 ± 0.13^{c}	1.18 ± 0.05^{b}	36.77 ± 0.18^{c}	6.20 ± 0.06^{a}	1.20 ± 0.02^{a}	1.81 ± 18.42^{a}	0.96 ± 0.02^{a}	13.63 ± 0.09^{c}
Storage temperature (°C)	$p \leq .01^{\dagger}$	$p = .72$	$p = .08$	$p = .16$	$p = .69$	$p = .05^{\dagger}$	$p = .80$	$p = .05$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
3	21.65 ± 0.05^{b}	6.11 ± 0.00^{a}	71.39 ± 0.11^{a}	1.12 ± 0.04^{a}	35.75 ± 0.14^{a}	6.41 ± 0.05^{b}	1.18 ± 0.02^{a}	1.86 ± 15.04^{a}	11.33 ± 0.01^{b}	5.48 ± 0.07^{a}
10	21.34 ± 0.05^{a}	6.11 ± 0.00^{a}	71.65 ± 0.11^{a}	1.20 ± 0.04^{a}	35.83 ± 0.14^{a}	6.27 ± 0.05^{a}	1.17 ± 0.02^{a}	1.82 ± 15.04^{a}	9.76 ± 0.01^{a}	8.63 ± 0.07^{b}
Storage time (day)	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .25$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .05$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
0	21.39 ± 0.08^{b}	6.18 ± 0.01^{c}	70.92 ± 0.17^{a}	1.14 ± 0.06^{a}	37.62 ± 0.23^{b}	6.10 ± 0.08^{a}	1.12 ± 0.03^{a}	1.76 ± 23.78^{a}	14.73 ± 0.02^{d}	3.53 ± 0.11^{a}
2	21.47 ± 0.08^{b}	6.17 ± 0.01^{c}	71.52 ± 0.17^{ab}	1.14 ± 0.06^{a}	35.88 ± 0.23^{a}	6.27 ± 0.08^{ab}	1.18 ± 0.03^{a}	1.82 ± 23.78^{ab}	10.62 ± 0.02^{c}	4.90 ± 0.11^{b}
4	22.25 ± 0.08^{c}	6.15 ± 0.01^{b}	71.77 ± 0.17^{b}	1.08 ± 0.06^{a}	35.20 ± 0.23^{a}	6.41 ± 0.08^{b}	1.21 ± 0.03^{a}	1.86 ± 23.78^{b}	8.95 ± 0.02^{a}	7.30 ± 0.11^{c}
8	21.37 ± 0.08^{b}	6.03 ± 0.01^{a}	71.76 ± 0.17^{b}	1.16 ± 0.06^{a}	35.11 ± 0.23^{a}	6.48 ± 0.08^{b}	1.22 ± 0.03^{a}	1.86 ± 23.78^{b}	8.89 ± 0.02^{a}	9.73 ± 0.11^{d}
10	21.00 ± 0.08^{a}	6.03 ± 0.01^{a}	71.62 ± 0.17^{b}	1.28 ± 0.06^{a}	35.13 ± 0.23^{a}	6.42 ± 0.08^{b}	1.15 ± 0.03^{a}	1.89 ± 23.78^{b}	9.53 ± 0.02^{b}	9.81 ± 0.11^{d}
Grand mean	21.50	6.11	71.52	1.16	35.79	6.34	1.18	1.84	10.54	7.05

Note: Results are expressed as mean ± SE. Values with different letters are statistically different at $p \leq .05$.

Abbreviations: A, air; B, Birgit; LC, Lady Claire; MA, modified atmosphere; SA, sodium ascorbate; SC, sodium chloride; V, vacuum; W, water.

†Statistically significant variable at $p \leq .05$.

TABLE 2 Influence of cultivar, anti-browning agent, package atmosphere, storage temperature, and storage time on sensory properties of raw fresh-cut potato

Source of variation	Color	Odor	Off-odor	Moistness	Firmness
Cultivar	$p \leq .01^{\dagger}$	$p = .13$	$p \leq .01^{\dagger}$	$p = .07$	$p = .06$
B	1.53 ± 0.03^{a}	2.40 ± 0.07^{a}	1.57 ± 0.04^{a}	2.02 ± 0.05^{a}	3.24 ± 0.03^{a}
LC	2.84 ± 0.03^{b}	2.25 ± 0.07^{a}	1.92 ± 0.04^{b}	1.90 ± 0.05^{a}	3.16 ± 0.03^{a}
Anti-browning agent	$p \leq .01^{\dagger}$	$p = .26$	$p = .18$	$p \leq .01^{\dagger}$	$p = .85$
W	2.40 ± 0.03^{b}	2.25 ± 0.08^{a}	1.73 ± 0.04^{a}	1.60 ± 0.06^{a}	3.21 ± 0.04^{a}
SC (1%)	2.29 ± 0.03^{b}	2.29 ± 0.08^{a}	1.81 ± 0.04^{a}	2.15 ± 0.06^{b}	3.18 ± 0.04^{a}
SA (2%)	1.86 ± 0.03^{a}	2.44 ± 0.08^{a}	1.70 ± 0.04^{a}	2.12 ± 0.06^{b}	3.20 ± 0.04^{a}
Package atmosphere	$p \leq .01^{\dagger}$	$p = .38$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .05$
A	2.43 ± 0.03^{c}	2.40 ± 0.08^{a}	1.42 ± 0.04^{a}	1.51 ± 0.06^{a}	3.22 ± 0.04^{a}
V	1.93 ± 0.03^{a}	2.34 ± 0.08^{a}	1.80 ± 0.04^{b}	2.20 ± 0.06^{b}	3.13 ± 0.04^{a}
MA	2.20 ± 0.03^{b}	2.24 ± 0.08^{a}	2.02 ± 0.04^{c}	2.17 ± 0.06^{b}	3.25 ± 0.04^{a}
Storage temperature (°C)	$p \leq .01^{\dagger}$	$p = .40$	$p \leq .01^{\dagger}$	$p = .41$	$p = .87$
3	2.24 ± 0.03^{b}	2.37 ± 0.07^{a}	1.66 ± 0.04^{a}	1.93 ± 0.05^{a}	3.20 ± 0.03^{a}
10	2.12 ± 0.03^{a}	2.28 ± 0.07^{a}	1.83 ± 0.04^{b}	1.99 ± 0.05^{a}	3.20 ± 0.03^{a}
Storage time (day)	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
0	1.70 ± 0.05^{a}	2.67 ± 0.11^{b}	1.08 ± 0.06^{a}	2.40 ± 0.07^{c}	3.03 ± 0.05^{a}
2	1.85 ± 0.05^{a}	2.70 ± 0.11^{b}	1.03 ± 0.06^{a}	1.72 ± 0.07^{a}	3.33 ± 0.05^{bc}
4	2.03 ± 0.05^{c}	2.46 ± 0.11^{b}	1.37 ± 0.06^{b}	1.70 ± 0.07^{a}	3.44 ± 0.05^{c}
8	2.59 ± 0.05^{b}	1.98 ± 0.11^{a}	2.27 ± 0.06^{c}	1.92 ± 0.07^{ab}	3.16 ± 0.05^{ab}
10	2.74 ± 0.05^{b}	1.83 ± 0.11^{a}	2.98 ± 0.06^{d}	2.05 ± 0.07^{b}	3.04 ± 0.05^{a}
Grand mean	2.18	2.33	1.75	1.96	3.20

Note: Results are expressed as mean ± SE. Values with different letters are statistically different at $p \leq .05$.
Abbreviations: A, air; B, Birgit; LC, Lady Claire; MA, modified atmosphere; SA, sodium ascorbate; SC, sodium chloride; V, vacuum; W, water.
†Statistically significant variable at $p \leq .05$.

Samples treated with both ABA showed slightly higher pH value compared to control, probably due to pH value of solutions itself, where sodium chloride solution is neutral and sodium ascorbate is slightly alkaline (Marshall at al., 2000). Calder, Kash, et al. (2011), as well as Ierna et al. (2016), also concluded that pH of treated FCP depends on pH of ABA. The MA packaged samples were less acidic than the samples packaged in air and vacuum, but those differences were numerically very small (MA 6.13, air and vacuum 6.10).

Also, samples became more acidic during storage, where pH of 6.18, measured at the beginning of the storage, decreased to 6.03 at the 10th day. Rocha et al., (2003) also recorded potato pH decrease during storage. This decrease is probably result of respiration, where CO_2 concentration increases during storage and by its dissolution into the liquid medium of the cell contributes to acidity increase (Soliva-Fortuny, Grigelmo-Miguel, Hernando, Lluch, & Martin-Belloso, 2002).

3.2 | Color analysis

The results of color measurement are given in Table 1. As can be seen, cultivar and package atmosphere significantly affected all recorded color parameters (L^*, a^*, and b^*), while ABA type and storage time significantly influenced only on L^* and b^*($p \leq .05$). Storage temperature did not show significant influence on samples color parameters ($p \geq .05$). Grand mean established for L^* was 71.52, while for a^* it was 1.16 and 35.79 for b^*.

Cv. Birgit showed brighter color (L^* = 72.87) in comparison to cv. Lady Claire (L^* = 70.17). This could be due to cultivar specificities, lower L^* value indicates potato browning (Tsouvaltzis et al., 2011). This statement can also be supported with European potato database, where it is stated that cv. Birgit is very resistant to enzymatic browning.

Although both cultivars are described with positive a^* value (cv. Birgit = 2.04, cv. Lady Claire = 0.28), meaning that its color belongs to red color area, it can be noticed that a^* value measured in cv. Lady Claire tubers is near 0 and in that way more inclined to the green part (negative a^* values) of the spectrum than cv. Birgit. Furthermore, based on the recorded b^* values, color of both cultivars belongs to yellow area (positive b^* value), where cv. Birgit showed more yellowness (39.68) compared to cv. Lady Claire (31.89). These results are in accordance with European Cultivated Potato Database (2017) about cultivar flesh color, where primary cv. Birgit tuber flesh color is yellow and primary cv. Lady Claire tuber flesh color is light yellow. Differences between five cultivars were also noticed by Cabezas-Serrano et al. (2009), where L^* and

TABLE 3 Influence of cultivar, anti-browning agent, package atmosphere, storage temperature, and storage time on sensory properties of boiled fresh-cut potato

Source of variation	Color	Odor	Off-odor	Moistness	Firmness	Creaminess	Characteristic taste	Sweet taste	Sour taste	Salty taste	Bitter taste	Off-taste
Cultivar	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .27$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p = .05$	$p = .65$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
B	1.16 ± 0.03^{a}	3.06 ± 0.07^{a}	1.29 ± 0.03^{a}	2.11 ± 0.06^{a}	2.11 ± 0.04^{a}	3.49 ± 0.05^{b}	3.31 ± 0.06^{b}	1.24 ± 0.02^{b}	1.22 ± 0.03^{a}	1.04 ± 0.01^{a}	1.06 ± 0.02^{a}	1.22 ± 0.03^{a}
LC	2.13 ± 0.03^{b}	2.77 ± 0.07^{b}	1.46 ± 0.03^{b}	2.02 ± 0.06^{a}	2.27 ± 0.04^{b}	2.84 ± 0.05^{a}	3.01 ± 0.06^{a}	1.13 ± 0.02^{a}	1.30 ± 0.03^{a}	1.05 ± 0.01^{a}	1.13 ± 0.02^{b}	1.44 ± 0.03^{b}
Anti-browning agent	$p \leq .01^{\dagger}$	$p = .99$	$p = .33$	$p = .39$	$p = .78$	$p = .56$	$p = .20$	$p \leq .01^{\dagger}$	$p = .20$	$p = .14$	$p = .24$	$p \leq .01^{\dagger}$
W	1.79 ± 0.03^{b}	2.91 ± 0.08^{a}	1.36 ± 0.04^{a}	2.14 ± 0.07^{a}	2.22 ± 0.05^{a}	3.12 ± 0.06^{a}	3.09 ± 0.07^{a}	1.13 ± 0.03^{a}	1.31 ± 0.03^{a}	1.07 ± 0.02^{a}	1.12 ± 0.02^{a}	1.41 ± 0.04^{b}
SC (1%)	1.62 ± 0.03^{a}	2.90 ± 0.08^{a}	1.42 ± 0.04^{a}	2.00 ± 0.07^{a}	2.17 ± 0.05^{a}	3.17 ± 0.06^{a}	3.14 ± 0.07^{a}	1.15 ± 0.03^{a}	1.25 ± 0.03^{a}	1.03 ± 0.02^{a}	1.09 ± 0.02^{a}	1.29 ± 0.04^{ab}
SA (2%)	1.52 ± 0.03^{a}	2.92 ± 0.08^{a}	1.35 ± 0.04^{a}	2.06 ± 0.07^{a}	2.17 ± 0.05^{a}	3.21 ± 0.06^{a}	3.26 ± 0.07^{a}	1.27 ± 0.03^{b}	1.22 ± 0.03^{a}	1.03 ± 0.02^{a}	1.07 ± 0.02^{a}	1.28 ± 0.04^{a}
Package atmosphere	$p \leq .01^{\dagger}$	$p = .99$	$p \leq .01^{\dagger}$	$p = .93$	$p \leq .01^{\dagger}$	$p = .10$	$p = .15$	$p = .15$	$p \leq .01^{\dagger}$	$p = .37$	$p = .61$	$p \leq .01^{\dagger}$
A	1.93 ± 0.03^{c}	2.91 ± 0.08^{a}	1.36 ± 0.04^{a}	2.07 ± 0.07^{a}	2.00 ± 0.05^{a}	3.26 ± 0.06^{a}	3.19 ± 0.07^{a}	1.21 ± 0.03^{a}	1.19 ± 0.03^{a}	1.03 ± 0.02^{a}	1.08 ± 0.02^{a}	1.28 ± 0.04^{a}
V	1.35 ± 0.03^{a}	2.92 ± 0.08^{a}	1.26 ± 0.04^{a}	2.05 ± 0.07^{a}	2.18 ± 0.05^{a}	3.14 ± 0.06^{a}	3.25 ± 0.07^{a}	1.20 ± 0.03^{a}	1.22 ± 0.03^{a}	1.06 ± 0.02^{a}	1.09 ± 0.02^{a}	1.29 ± 0.04^{a}
MA	1.65 ± 0.03^{b}	2.91 ± 0.08^{a}	1.50 ± 0.04^{b}	2.09 ± 0.07^{a}	2.38 ± 0.05^{b}	3.10 ± 0.06^{a}	3.06 ± 0.07^{a}	1.14 ± 0.03^{a}	1.37 ± 0.03^{b}	1.04 ± 0.02^{a}	1.11 ± 0.02^{a}	1.42 ± 0.04^{b}
Storage temperature (°C)	$p = .24$	$p = .93$	$p = .88$	$p = .97$	$p = .48$	$p = .14$	$p = .47$	$p = .65$	$p = .73$	$p = .42$	$p = .53$	$p = .98$
3	1.66 ± 0.03^{a}	2.91 ± 0.07^{a}	1.38 ± 0.03^{a}	2.07 ± 0.06^{a}	2.16 ± 0.04^{a}	3.12 ± 0.05^{a}	3.13 ± 0.06^{a}	1.17 ± 0.02^{a}	1.27 ± 0.03^{a}	1.03 ± 0.01^{a}	1.09 ± 0.02^{a}	1.33 ± 0.03^{a}
10	1.62 ± 0.03^{a}	2.92 ± 0.07^{a}	1.37 ± 0.03^{a}	2.07 ± 0.06^{a}	2.21 ± 0.04^{a}	3.21 ± 0.05^{a}	3.19 ± 0.06^{a}	1.19 ± 0.02^{a}	1.25 ± 0.03^{a}	1.05 ± 0.01^{a}	1.10 ± 0.02^{a}	1.33 ± 0.03^{a}
Storage time (day)	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$	$p \leq .01^{\dagger}$
0	1.22 ± 0.04^{a}	3.68 ± 0.11^{c}	1.07 ± 0.05^{ab}	2.38 ± 0.09^{b}	1.95 ± 0.07^{b}	3.92 ± 0.07^{c}	3.92 ± 0.09^{b}	1.23 ± 0.04^{bc}	1.12 ± 0.04^{a}	1.00 ± 0.02^{a}	1.00 ± 0.03^{a}	1.15 ± 0.05^{a}
2	1.37 ± 0.04^{a}	3.02 ± 0.11^{b}	0.90 ± 0.05^{a}	1.84 ± 0.09^{a}	1.65 ± 0.07^{a}	3.33 ± 0.07^{b}	3.69 ± 0.09^{b}	1.36 ± 0.04^{c}	1.14 ± 0.04^{a}	1.13 ± 0.02^{b}	1.08 ± 0.03^{ab}	1.08 ± 0.05^{a}
4	1.70 ± 0.04^{c}	2.97 ± 0.11^{b}	1.24 ± 0.05^{b}	1.96 ± 0.09^{a}	2.32 ± 0.07^{c}	2.99 ± 0.07^{a}	3.24 ± 0.09^{c}	1.15 ± 0.04^{ab}	1.12 ± 0.04^{a}	1.04 ± 0.02^{a}	1.11 ± 0.03^{b}	1.24 ± 0.05^{ab}
8	1.91 ± 0.04^{b}	2.49 ± 0.11^{a}	1.67 ± 0.05^{c}	2.04 ± 0.09^{ab}	2.65 ± 0.07^{d}	2.79 ± 0.07^{a}	2.51 ± 0.09^{a}	1.05 ± 0.04^{a}	1.32 ± 0.04^{b}	0.99 ± 0.02^{a}	1.15 ± 0.03^{b}	1.38 ± 0.05^{b}
10	2.03 ± 0.04^{b}	2.40 ± 0.11^{a}	1.99 ± 0.05^{d}	2.12 ± 0.09^{ab}	2.36 ± 0.07^{c}	2.79 ± 0.07^{a}	2.46 ± 0.09^{a}	1.12 ± 0.04^{ab}	1.60 ± 0.04^{c}	1.04 ± 0.02^{a}	1.13 ± 0.03^{b}	1.78 ± 0.05^{c}
Grand mean	1.64	2.91	1.37	2.07	2.19	3.17	3.16	1.18	1.26	1.04	1.09	1.33

Note: Results are expressed as mean ± SE. Values with different letters are statistically different at $p \leq .05$.

Abbreviations: A, air; B, Birgit; LC, Lady Claire; MA, modified atmosphere; SA, sodium ascorbate; SC, sodium chloride; V, vacuum; W, water.

†Statistically significant variable at $p \leq .05$.

b^* values of Marabel were the most similar to values obtained for cultivars in our study, with an exception with a^*, which was lower (L^* = 70.9, a^* = −5.1, b^* = 30.5).

Comparing the samples treated with different ABA, the highest L^* values were obtained in samples treated with sodium ascorbate. Calder, Skonberg, Davis-Dentici, Hughes, and Bolton (2011) treated potato slices with different ABA (ascorbic acid, citric acid, catechin, SAS, and NatureSeal-PS 10) as well as ozone and also observed the L^* value increase in treated samples compared to control (samples treated with distilled water and distilled water with ozone) during refrigerated storage (4°C) for 28 days. Rocculi et al., (2007) used citric acid, ascorbic acid, and L-cysteine for browning prevention of FCP and after 24 hr air exposure all treated samples showed higher L^* values compared to control. As for a^* and b^* values, potato a^* value did not differ much between the applied solutions, while b^* value showed minor increase in potatoes immersed in both salt solutions in comparison with control, indicating its positive effect on yellowness retention. Similar results were reported in Calder, Skonberg, et al. (2011) study, where samples immersed in distilled water and distilled water with ozone had significantly lower b^* values during storage than samples treated with ABA NatureSeal and sodium acid sulfate.

Vacuum and MA packaged samples showed good retention of bright and yellow color (vacuum L^* = 72.45, b^* = 36.77; MA L^* = 71.50, b^* = 36.04) in comparison with samples packaged in air, which were the darkest and least yellow colored (L^* = 70.61, b^* = 34.54). These results indicate that in samples packaged in vacuum and MA, enzymatic browning is prevented due to formed higher level of CO_2, which could inactivate some enzymes in the Krebs cycle (Kader, 1986; Rocculi et al., 2009). Obtained a^* values varied among types of package atmosphere, where vacuum packaged samples were the most prone to greenness considering its lowest a^* value among investigated package atmospheres.

Color parameters slightly varied during storage, but L^* values increased by the end of storage, while b^* value decreased. Rocha et al. (2003) documented similar results.

According to the above, it can be concluded that the oxygen reduction present in vacuum and MA packaged samples along with application of sodium chloride and sodium ascorbate ABA contributed to the reduction of the potato browning during storage, what is in accordance with results of Calder, Skonberg, et al. (2011).

3.3 | Texture analysis

Firmness, elasticity, and work required for chewing were determined in order to provide samples textural properties (Table 1). Firmness and work significantly differed by ABA, package atmosphere and time of storage ($p \leq .05$). Storage temperature had significant influence only on samples' firmness ($p \leq .05$), while examined textural properties did not show significant differences upon cultivar type ($p \geq .05$). Grand means were as follows: for firmness 6.34 N, for elasticity 1.18 mm, and for work 1.84 J.

As presented in Table 1, the firmness, elasticity, and work of examined cultivars were pretty similar, unlike their values between samples treated with ABA, where the highest firmness was detected in sodium chloride-treated samples (6.51 N), followed by control (6.32 N), while samples treated with sodium ascorbate showed the lowest firmness (6.18 N). It is interesting that sodium chloride samples also had the highest dry matter content. As sodium chloride binds water and thereby reduces its activity (Hutton, 2002), it could cause increased firmness. Pearson's coefficient showed strong correlation between potatoes firmness and work required for chewing (Table 4).

Considering package atmosphere, air packaged samples distinguished by the highest firmness (6.54 N), while samples packaged in vacuum and MA proved to be softer (vacuum = 6.26 N, MA = 6.20 N). This could be due to turgor pressure decrease, which is directly related to water loss, and enzymes responsible for softening (pectinesterase, polygalacturonase, and β-galactosidase) come more easily in contact with substrates (Rocculi et al., 2009).

The firmness and work of the samples stored at 3°C were slightly higher compared to samples stored at 10°C. This could be explained by the greater activity of endogenous enzymes on the cell wall and growth of microorganisms influenced by higher temperature (Rocha et al., 2003).

Observing the effect of storage time, it can be seen that firmness, as well as work, increased during storage. These textural changes may appear due to increased water loss that is common after peeling and cutting of fresh-cut products, after removal of an external protective periderm that prevents water loss during transpiration. In addition, wounding response can cause hardening due to cross-linking of cell wall components and suberin deposition, where potato becomes firmer over time (Rocculi et al., 2009).

Generally, elasticity of all samples was almost equal. Interestingly, elasticity increased during storage, where it peaked at the 8th day, showing good cooking quality, since potatoes with higher elasticity do not disintegrate during cooking, and therefore greater potato elasticity is desirable property (Jansky, 2010).

3.4 | Monitoring of package gas composition

The changes of CO_2 and O_2 concentrations in the headspace above the packaged potato slices are given in Table 1. Grand mean of O_2 and CO_2 contents were 10.54% and 7.05%, respectively, and they were significantly affected by all investigated influences ($p \leq .05$) (Table 1).

The value of the CO_2 content is higher in cv. Lady Claire samples than in cv. Birgit samples. Regard to concentration of released CO_2, which is a measure of respiration intensity (Lisinska & Leszczynski, 1989), it could be concluded that cv. Lady Claire showed more pronounced respiration rate than cv. Birgit. Observed potato cultivar effect on respiration intensity is in accordance with previous results, where intensity of respiration was tested on cv. Sowa and Krokus (Lisinska & Leszczynski, 1989).

Considering the impact of ABA, minor differences in content of O_2 and CO_2 between solution types can be observed, where the highest

TABLE 4 Correlation coefficients for physical and chemical parameters and sensory properties of raw and boiled fresh-cut potato

	L^*	a^*	b^*	Firmness (N)	Work (J)	O_2 (%)	CO_2 (%)	Color RFCP	Color BFCP	Odor RFCP	Odor BFCP	Off-odor RFCP	Off-odor BFCP	Firmness BFCP	Creaminess BFCP	Characteristic taste BFCP	Sour taste BFCP	Off-taste BFCP
L^*	1	.41*	.66*	−.30*	−.14	−.38*	.27*	−.52*	−.56*	−.01	.02	.02	−.01	.01	.10	.02	.03	−.11
a^*		1	.68*	.09	.05	−.06	−.10	−.36*	−.25*	.11	.16*	−.18*	−.01	−.22*	.26*	.12	−.14	−.17*
b^*			1	−.12	−.09	−.15*	.01	−.71*	−.71*	.22*	.30*	−.19*	−.20*	−.22*	.43*	.29*	−.15*	−.34*
Firmness (N)				1	.82*	.11	−.11	.22*	.24*	−.06	−.18*	.01	.14	.09	−.12	−.14	−.04	−.01
Work (J)					1	.05	−.07	.19*	.19*	−.11	−.22*	.07	.13	.12	−.17*	−.19*	.00	.02
O_2 (%)						1	−.77*	−.02	.04	.23*	.25*	−.26*	−.17*	−.26*	.24*	.26*	−.24*	−.12
CO_2 (%)							1	.17*	.06	−.42*	−.34*	.53*	.28*	.40*	−.30*	−.45*	.45*	.28*
Color RFCP								1	.85*	−.51*	−.53*	.49*	.45*	.32*	−.50*	−.58*	.39*	.51*
Color BFCP									1	−.34*	−.42*	.31*	.40*	.28*	−.48*	−.48*	.24*	.40*
Odor RFCP										1	.79*	−.89*	−.71*	−.46*	.44*	.80*	−.62*	−.65*
Odor CFCP											1	−.73*	−.76*	−.52*	.61*	.86*	−.52*	−.62*
Off-odor RFCP												1	.75*	.49*	−.50*	−.79*	.70*	.74*
Off-odor BFCP													1	.35*	−.49*	−.73*	.60*	.83*
Firmness BFCP														1	−.64*	−.60*	.37*	.30
Creaminess BFCP															1	.68*	−.40*	−.49*
Characteristic taste BFCP																1	−.66*	−.68*
Sour taste BFCP																	1	.65*
Off-taste BFCP																		1

Abbreviations: BFCP, boiled fresh-cut potato; RFCP, raw fresh-cut potato.

*$p \leq .05$.

concentration of O_2 was detected in samples treated with water and the highest CO_2 content was observed in samples treated with sodium chloride solution. Samples treated with sodium ascorbate showed the lowest levels of both gases. Cacace et al. (2002) reported that less CO_2 is accumulated in ABA-treated samples than in control samples at both storage temperatures and they assumed that chemical treatment led to inhibition of respiration in potato cell. In Beltran et al. (2005) study no significant differences were observed in the package atmospheres between washing treatments through the storage period, where they used different ABA (sodium sulfite, sodium hypochlorite, Tsunami) and packaging type (passive MA) compared to our study.

Gas composition of packages showed reverse trend between O_2 and CO_2 content depending on the used package atmosphere. Understandably, MA packaged samples had the lowest O_2 (0.96%) and the highest CO_2 level (13.63%), while in other two package atmospheres higher O_2 and lower CO_2 concentrations were recorded, respectively. Minor differences in % O_2 and % CO_2 observed between air and vacuum packaged samples are comprehensible, since gas composition in samples packaged in vacuum is actually gas composition of normal air (21.0% O_2, 0.04% CO_2, and 78.0% N_2), but at reduced partial gas pressure (Ahvenainen, 1996).As expected, the highest O_2 and the lowest CO_2 contents were detected in air packaged samples. Farber et al. (2003) in their review concluded that even with recommended percentage of O_2 in MA packaging (between 1% and 5%), O_2, content will reach levels below 1%.

In samples stored at 10°C, higher concentration of CO_2 was present compared to samples stored at 3°C, because higher storage temperature increases respiration rate (Ghazavi & Houshmand, 2010). Cacace et al. (2002) also reported similar results, where they concluded that samples stored at 6°C have higher respiration rate than ones stored at 1°C. Furthermore, lower CO_2 content at 3°C is also due to increased CO_2 solubility at lower temperatures.

During storage time, level of O_2 decreased and level of CO_2 increased. The greatest changes in gas levels were observed by the 4th day, while afterward concentrations of O_2 and CO_2 were almost stabile. In research of Beltran et al. (2005) steady state of gases was achieved after 5 days storage of cv. Monalisa at 4°C in LDPE film packaged in vacuum and passive MA treated with sodium sulfite (2 g/L), Tsunami (300 mg/L), ozone (20 mg/L) and ozone–Tsunami ABA.

3.5 | Sensory analysis

3.5.1 | Raw potato samples

Raw FCP samples were sensory evaluated for color (as browning intensity), odor, off-odor, moistness, and firmness. Statistical analysis (Table 2) showed significant influence of storage time on all evaluated sensory properties, while package atmosphere significantly affected color, off-odor and moistness ($p \leq .05$). Furthermore, ABA had significant effect on color and moistness, while color and off-odor significantly differed by cultivar and storage temperature.

It is obvious that cv. Lady Claire was evaluated with higher grades for undesirable sensory properties of browning intensity and off-odor, as well as with lower grade for its odor compared to cv. Birgit. These results are in accordance with previously mentioned results of color analysis, indicating that panelists also detected cv. Lady Claire's tendency to faster appearance of undesirable changes. In addition, sensory evaluated color of raw samples had medium correlation with L^* parameter, while it strongly correlated with b^* value (Table 4).

Considering the influence of ABA on sensory attributes of raw samples, it can be seen that samples treated with ABA were lower graded for browning opposed to control sample, where sample treated with sodium ascorbate emphasized with the lowest grade for intensity of browning, which points that this agent showed more efficiency in anti-browning prevention. This panelists' observation corresponds to previously discussed colorimetric results. Ierna et al. (2016) also reported significant differences in sensory detected browning of the potato slices after treatments with ABA (sterile deionized water, 0.2% sodium bisulfite, 2% ascorbic acid +2% citric acid) as well as cultivar differences and their interactions. Furthermore, it can be noticed that moistness of samples treated with ABA was higher graded in comparison with control samples. Moistness is desirable sensory property of fresh-cut products, since consumers do not prefer dried and hard potato slices (Rocculi et al., 2009).

As for package atmosphere, the smallest color change was visible in vacuum packaged samples. Samples packaged in MA were slightly higher scored for the same attribute, while the largest color change was noticed among the control samples. Obtained results are in accordance with results of Beltran et al. (2005) study, which showed that vacuum packaging better preserved potato strip appearance than MA (passive). MA samples were also graded as the least odored and with the highest off-odor. This is probably due to highest level of CO_2, what is confirmed with medium correlation between these parameters, and the lowest O_2 content present in MA packaged samples. Content of O_2 less than 1% lead to the formation of off-flavors (Cacace et al., 2002). Again, lowest moistness was recorded in control samples, contrarily to vacuum and MA packaged samples, which were the moistest, probably due to different water vapor permeability of packaging material used. Rocha et al. (2003) also noticed lower moisture loss in potatoes packaged in PE/PA bags.

Brownness appearance was more noticeable in samples stored at 3°C. The same samples retained more pronounced odor and lower presence of off-odor in comparison with samples stored at 10°C, but those differences were numerically negligible. This is understandable, since growth of spoilage flora during refrigeration is slower (Gorris & Peppelenbos, 1992). Cacace et al., (2002) also investigated the effect of temperature (1 and 6°C) on sensory characteristic of FCP cv. Russet Burbank. In their research color grades of FCP (lower browning) stored at 6°C were slightly better during first seven days of storage, but afterwards FCP color stored at 1°C was better rated. Furthermore, similar to our results, samples stored at 6°C were less favorable for appearance and odor than samples stored at 1°C.

Based on the panelists' observation, it is evident that undesirable sensory changes appeared with storage duration. Therefore, samples were expectedly more inclined to browning, as well as odor decrease and increase of off-odor toward the end of storage. Same results for browning during storage were present in several samples in Cacace et al. (2002) research. In addition, the decrease of moistness reflected on firmness increase by the 4th storage day, but by the end of storage firmness was rated with the same value as for the 1st day of storage.

3.5.2 | Boiled potato samples

In order to provide better sensory insight of FCP samples used in this study, primarily the taste attributes, all raw samples were boiled and sensory evaluated as well. Table 3 provides the data about influence of examined sources of variation on the color (browning intensity), odor, off-odor, moistness, firmness, creaminess, and characteristic taste, as well as sweet, sour, salty, bitter, and off-taste of boiled FCP, where is evident that storage time significantly affected all tested sensory properties ($p \leq .05$). Cultivar had also significant effect on the majority of sensory attributes, except on moistness, and sour and salty taste ($p \geq .05$). Package atmosphere significantly influenced on color, off-odor, firmness, and sour and off-taste, while samples significantly differed in color, sweet and off-taste by the applied ABA.

Similar to sensory results of raw samples, boiled cv. Birgit samples were described with more pronounced desirable sensory properties, where they were higher graded for odor, moistness, creaminess, and characteristic and sweet taste, opposed to cv. Lady Claire samples, which were evaluated as more prone to browning with more noticeable off-odor and higher firmness, as well the sour, bitter, and off-taste. Higher firmness of cv. Lady Claire could be related to its higher dry matter content in comparison with cv. Birgit. However, less firmness along with higher moistness enhances the potato creaminess, what is desirable property for boiled potato, where cv. Birgit, being commercial potato cultivar, showed its advantage over cv. Lady Claire. Cultivar differences in sensory characteristics were also confirmed by Thybo, Christiansen, Kaack, and Petersen (2006).

Among ABA, the control samples and ones treated with sodium ascorbate have mostly differed. Sodium ascorbate samples were evaluated as least brown in parallel with being the creamiest and sweetest with the most pronounced characteristic taste. At the same time, control samples showed the greatest tendency to browning and expression of sour, bitter, and off-taste. Once again, sodium ascorbate showed its greater potential for color preservation without negative sensory effect.

Package atmosphere also showed sensory differences between samples. The most preserved color was detected in vacuum packaged samples, followed by ones packaged in MA and control samples were graded with the highest browning intensity. Observing the sensory scores for other evaluated attributes, it is evident that MA packaged samples were sensorially undesirable. They were scored with the lowest grades for creaminess, and characteristic and sweet taste, while they achieved the highest grades for off-odor, sour, bitter, and off-taste as well the firmness. Moreover, samples packaged in vacuum had the greatest pronounced characteristic taste and the least prominent off-odor.

Samples sensorially did not distinguish upon storage temperature, although slightly higher brownness and sour taste can be noticed in samples stored at 3°C, while samples stored at 10°C had slightly more expressed characteristic taste.

As expected, boiled potatoes became browner with more pronounced off-odor, sour, bitter, and off-taste during storage period. Also, the expression of odor, creaminess, and characteristic and sweet taste decreased by the latest storage day. In addition, potatoes characteristic taste and odor decrease strongly correlated with off-odor increase, as well as they showed medium correlation with sour taste increase (Table 4). Presence of undesirable taste attributes, such as bitter taste, is a result of synthesis and accumulations of volatile compounds and endogenous fermentative metabolite products (Rocculi et al., 2009). Furthermore, Thybo et al. (2006) stated that nonvolatile compounds, such as glycoalkaloids and certain phenols, could be responsible for potato bitterness. Moistness and firmness grades slightly varied during storage time, but moistness decreased and firmness increased at the end of storage.

Comparing the sensory evaluation results of raw and boiled potatoes, it is evident that boiled samples were evaluated with higher scores for characteristic odor and lower scores for off-odor than samples of raw potato. According to Thybo et al., (2006), group of volatiles are responsible for raw potato off-odor. Regard to this, it is possible that these compounds present in our raw samples evaporated during boiling and therefore decreased off-odor in boiled samples was noticed. Besides that, volatiles, which could contribute to characteristic potato odor, are possibly formed during boiling from precursors amino acids and sugars with nucleotides as potentiators (Thybo et al., 2006).

3.6 | Principal component analysis

Principal Component Analysis (PCA) was carried out in order to explore relationships among data and to reduce the number of studied variables. Obtained results are presented in Figure 1, where first two components explained 43.23% of total variance. As can be seen in Figure 1a, certain grouping appeared upon cultivar type. The majority of cv. Birgit samples placed above the PC1, while the largest number of cv. Lady Claire samples situated below the same principal component. Furthermore, partial grouping of samples by the storage time can be observed in Figure 1e, where samples at the beginning of storage (0 and 2nd day) are located on the right side of the plot and samples from 8th to 10th day of storage positioned mostly on the left side. The most discriminating variables were raw potatoes' L^* and b^* values, color, odor, off-odor, boiled potatoes' odor, off-odor, creaminess, and characteristic and off-taste, since they highly correlated with both principal components. Besides, strong correlation

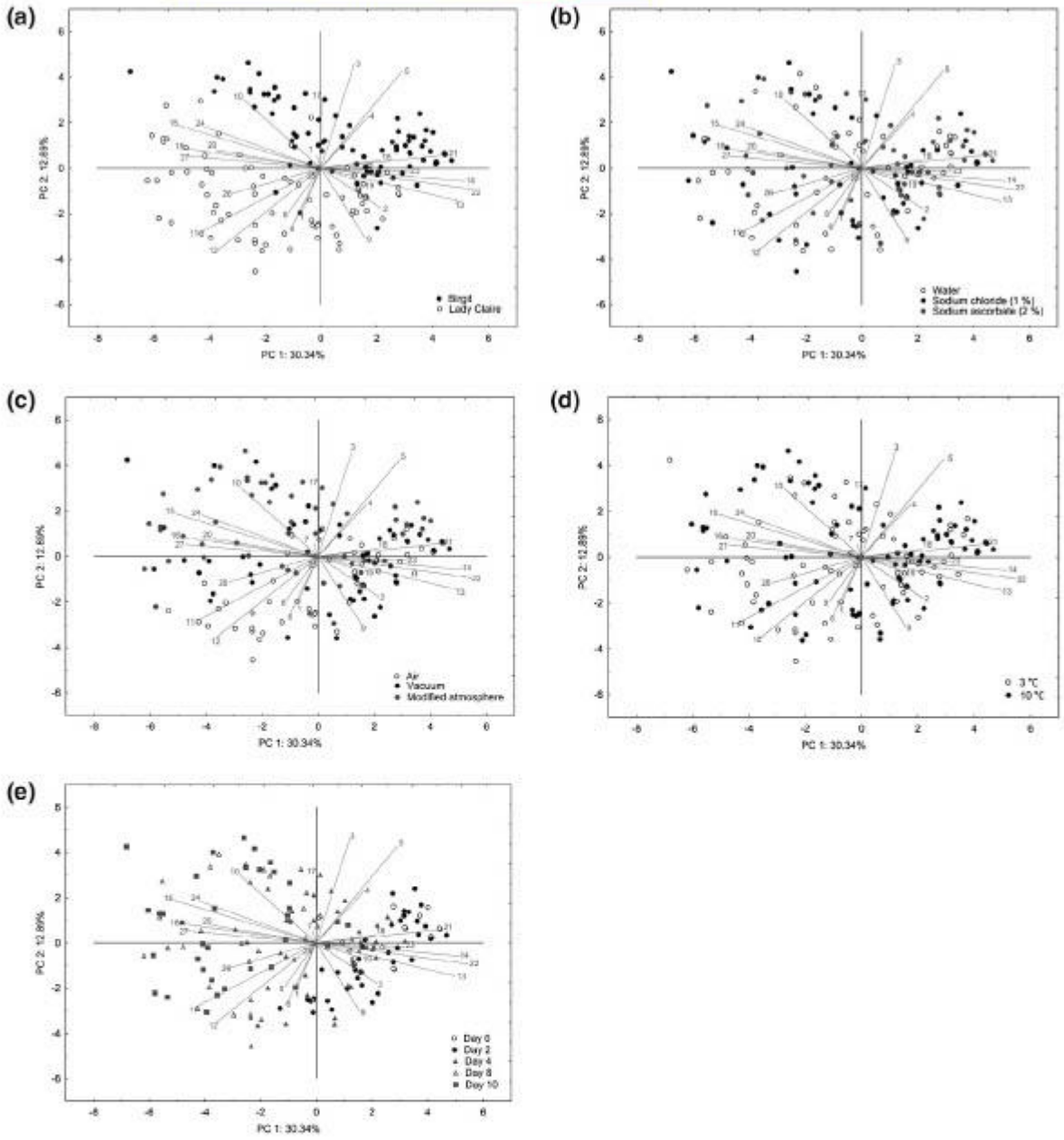

FIGURE 1 Distribution of the raw (R) and boiled (B) fresh-cut potato (FCP) samples in two dimensional coordinate system defined by first two principal components (PC1 and PC2) according to the applied conditions: a-influence of cultivar type; b-influence of anti-browning agent; c-influence of package atmosphere; d-influence of storage temperature; e-influence of storage time (1 – dry matter (%); 2 – pH value; 3 – L^*, 4 – a^*, 5 – b^*, 6 – firmness (N); 7 – elasticity (mm); 8 – work (J), 9 – O_2 (%), 10 – CO_2 (%), 11 – color-RFCP, 12 – color-BFCP, 13 – odor-RFCP, 14 – odor-BFCP, 15 – off-odor-RFCP, 16 – off-odor-BFCP, 17 – moistness-RFCP, 18 – moistness-BFCP, 19 – firmness-RFCP, 20 – firmness-BFCP, 21 – creaminess-BFCP, 22 – characteristic taste-BFCP, 23 – sweet taste-BFCP, 24 – sour taste-BFCP, 25 – salty taste-BFCP, 26 – bitter taste-BFCP, 27 – off-taste-BFCP)

was established between both principal components and following variables: % O_2. % CO_2, color, firmness, sweet, sour, and bitter taste of boiled potatoes, and therefore contribute to cultivars separation. This is in accordance with previously explained results. Based on the other applied conditions (ABA, package atmosphere and storage temperature), PCA did not show grouping of the examined samples (Figure 1b–d).

3.7 | Microbiological analysis

According to Guide for Microbiological Criteria for Food (Ministry of Agriculture, Fisheries and Rural Development of the Republic of Croatia, 2009), only potatoes which met these standards were used for this research. Also, acceptability of fresh-cut samples with respect to microbial population (aerobic mesophilic bacteria and

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TABLE 5 Microbiologically inappropriate samples

Storage time (day)								
2		4		8		10		
Aerobic mesophilic bacteria	*Enterobacteriaceae*	Aerobic mesophilic bacteria	*Enterobacteriaceae*	Aerobic mesophilic bacteria	*Enterobacteriaceae*	Aerobic mesophilic bacteria	*Enterobacteriaceae*
							B/W/3/A
					LC/SC/3/A		B/SC/3/A
							LC/SC/3/A
					B/SA/3/A	B/SA/3/A	B/SA/3/A
					LC/SA/3/A		LC/SA/3/A
				B/W/3/V	B/W/3/V	B/W/3/V	B/W/3/V
					LC/SC/3/MA	B/SC/3/V	LC/SC/3/MA
				B/W/3/V			B/SA/3/MA
							LC/SA/3/MA
B/SC/3/MA	B/W/3/MA	B/W/3/MA	B/W/3/MA	B/W/3/MA	B/W/3/MA	B/W/3/MA	B/W/3/MA
	LC/SC/3/MA		LC/SC/3/MA		LC/SC/3/MA		
B/SA/3/MA	B/SC/3/MA	LC/SC/3/MA	B/SC/3/MA	B/SC/3/MA	B/SC/3/MA	B/SC/3/MA	B/SC/3/MA
	LC/SC/3/MA		LC/SC/3/MA				
	LC/SA/3/MA	LC/SA/3/MA	LC/SA/3/MA	LC/SA/3/MA	LC/SA/3/MA		
							B/SC/10/A
							LC/SC/10/A

Abbreviations: 3/10, storage temperature (°C); A, air; B, Birgit; LC, Lady Claire; SA, sodium ascorbate (2%); SC, sodium chloride (1%); MA, modified atmosphere; W, water; V, vacuum.

Enterobacteriaceae) in FCP were examined according to previously mentioned guide, where recommended values of aerobic mesophilic bacteria in frozen fruit, vegetable and mushrooms should be $<10^5$ CFU/g and for *Enterobacteriaceae* in freshly sliced fruit, vegetables, mushrooms and sprouts $<10^3$ CFU/g.

Since most of samples were microbiologically correct until the 8th day of storage, list of only microbiologically inappropriate samples is given in Table 5. It can be noticed that MA packaged samples were the most unstable, as they were contaminated already at the 2nd day of storage. Almost all samples stored at 10°C fulfilled microbiological standards, what is not the case with 3°C stored FCP. This is possible due to lower O_2 levels at 10°C and decreased microbiological growth in such conditions. It was found in previous study that growth of aerobic mesophilic bacteria is correlated with O_2 decrease in package (Putnik, Bursać Kovačević, Herceg, & Levaj, 2016), what means that presence of oxygen is necessary for their growth. Hence, it is understandable that in samples stored at 10°C, where lower O_2 content was present, aerobic mesophilic bacteria were not detected. From the obtained results it is not visible that cultivar and ABA had impact on FCP microbiological activity.

4 | CONCLUSIONS

Results of this study showed that, although being relatively new cultivar on the market, cv. Birgit proved to be more appropriate for production of fresh-cut products, where it showed good maintenance of original color and pronounced desirable sensory properties. Furthermore, sodium ascorbate dipping, as well as vacuum packaging demonstrated promising preservation of fresh-cut potatoes' color and sensory up to 8 days. Hence, these conditions could represent the optimal pre-treatment and packaging type for best quality of cv. Birgit fresh-cut potatoes. Generally, examined temperatures (3° and 10°) did not have significant influence on the most investigated parameters.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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Chapter 3

Publication No. 2: Fresh-cut potato quality and sensory: Effect of cultivar, age, processing and cooking during storage

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Author contributions (Contributor Roles Taxonomy -CRediT)

Draženka Dite Hunjek-conducting an experiment, data analysis, drafting the manuscript
Tanja Pranjić-participation in one part of the analysis
Maja Repajić -contribution during statistical analysis and interpretation of the data, revising the manuscript
Branka Levaj -conceiving the original idea and designing the study, contribution to the discussion and data interpretation, and revising the manuscript

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Fresh-cut potato quality and sensory: Effect of cultivar, age, processing, and cooking during storage

Draženka Dite Hunjek, Tanja Pranjić, Maja Repajić, and Branka Levaj

Abstract: This work examined the influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on fresh-cut potatoes' (FCPs) physical, chemical, and sensory properties. Potato slices of cv. Birgit and Lady Claire tubers sampled during the first, fifth, and ninth months of storage were dipped in solutions of (1) sodium chloride (1%) and (2) sodium ascorbate (2%), and stored for 8 days in (1) vacuum and (2) active modified atmosphere (MAP) (10.0% CO_2, 3.0% O_2, and 87.0% N_2) at 10 °C. During storage, O_2 and CO_2 content (%) within packages was measured and samples were analyzed for weight loss, total solids (TS) and soluble solids (SS), pH, color, texture, and sensory properties of raw, boiled, fried, and baked FCP. Results showed that 9 months' aging had a significant impact on almost all investigated FCP properties, but differences among first, fifth, and ninth months were numerically feeble for some parameters in raw samples: TS changed from 22.14% to 20.98%, SS 5.53% to 6.93%, pH 6.02 to 5.98, L^* 70.10 to 68.87, C^* 35.75 to 36.70, $H°$ 89.29 to 88.15, and firmness 7.25 to 8.13N. Furthermore, 9 months of aging had no significant influence on the characteristic odor of raw, boiled, fried, and baked FCP and characteristic taste of fried and baked FCP, whereas boiled FCP characteristic taste remained unchanged for 5 months of aging. Fried FCP was better sensory evaluated than baked ones, cv. Birgit was more suitable for the FCP production compared to cv. Lady Claire as well as vacuum packaging and sodium ascorbate better preserved samples quality and sensory than sodium chloride and MAP.

Keywords: browning, fresh-cut potato, packaging, sensory, tubers age

Practical Application: This study could be helpful to fresh-cut potato (FCP) producers because results indicate that for FCP processing, along with the selection of cultivar, antibrowning agent, and packaging type, tubers' age also requires attention. A further contribution of this research is related to the adequate way of FCP cooking, where frying shows the best results according to the quality and sensory assessment.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is a perennial herb spread worldwide. In 2018, its production amounted 368 million tons (FAO, 2020). After harvesting, potato is subjected to the curing process that includes storage at 15 °C/14 days in dry conditions to promote dormancy and extend storage time (Wang et al., 2015). Afterward, storage temperature is lowered (0.5 °C/day) and potato can be stored in the warehouse up to 10 months under controlled temperature, relative humidity, and atmosphere. Table potatoes are usually stored at 4 to 5 °C, whereas processing potatoes are stored at 6 to 10 °C and recommended relative humidity >95% (Wustman & Struik, 2007). Hence, potato is often included and preferred in daily meal due to its durability through the whole year as well as various ways of its preparation (baked, roasted, boiled, fried, steamed, and microwaved) (Jansky, 2010).

Because the modern lifestyle leaves less time for preparing meals, the growing trend of food that requires short-term preparation is present for the last few decades (Wang et al., 2015), leading to the increased popularity and availability of fresh-cut fruits and vegetables, including fresh-cut potato (FCP). According to "The International Fresh-Cut Produce Association," fresh-cut products are defined as fruits and vegetables physically changed but still fresh or cleansed and 100% usable packaged with high nutritional value, convenience, unchanged taste, and retained freshness (IFPA, 1999). Fresh-cut fruits and vegetables have been on the U.S. market for about 30 years and its production has been growing steadily in all developed countries (Silva, Bastos, Wurlitz, Barros, & Mangan, 2012). In spite of the advantages of these products, especially due to their convenience and simplicity of use, they also have disadvantages, primarily in their extreme sensitivity and short shelf life. Potatoes' tendency for browning is a known feature that could decrease the product quality. Among numerous potato cultivars, scientific literature tested not so many cultivars for fresh-cut processing, for example, cv. Safrane, Liseta, Ariana, and Spunta, where cv. Safrane accomplished the best suitability according to the browning potential and postcut performance in general (Cornacchia, Cabezas-Serrano, Amodio, & Colelli, 2011).

Storage conditions and storage time also influence the physical and chemical properties of raw FCP, which could negatively reflect on the quality and general acceptance of cooked FCP.

During storage, tubers lose fresh weight through respiration, where they use part of dry matter (starch) for energy supply. Also,

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tubers' weight loss occurs during transpiration (water loss) (Wustman & Struik, 2007). This results in pH decrease and dry matter reduction during storage (Jansky, 2010). Furthermore, the concentration of reducing sugars in potato increases during storage due to the conversion of starch into sugars. That conversion, so called "low-temperature sweetening," is especially pronounced when potatoes are stored at lower temperatures (Kaul, Kumar, Hooda, & Sonkusare, 2010). Also, sprouting leads to starch conversion into reducing sugars as well as tubers' weight loss during storage, what should be reduced by antisprouting agents (Kaul et al., 2010; Wustman & Struik, 2007). Starch degradation, cells elasticity reduction, and water loss result with the less mealy texture of cooked potato (Jansky, 2010).

Storage could have a positive impact on flavor. Fatty acids content increases during storage, whereas further thermal processing (baking and boiling) forms aldehydes and ketones, which enrich aroma and contribute to taste fullness. Also, the storage length increases the content of reducing sugars and free amino acids, which form products with a positive impact on the taste through their involvement in Maillard reaction at high temperatures (Jansky, 2010).

Although cv. Birgit, as a recent cultivar, is unsusceptible to browning and cv. Lady Claire is well-known industrial cultivar mostly intended for chips industry, their behavior in terms of fresh-cut processing, especially within tubers' age, is unexplored according to the available scientific literature.

Hence, this comprehensive study aimed to examine the suitability and stability of two potato cultivars (cv. Birgit and Lady Claire) affected by tubers' aging, FCP processing, and its storage as well as the applied cooking process. Therefore, physical, chemical, and sensory characteristics of FCP produced from 1, 5, and 9 month-old tubers, treated with antibrowning agents, vacuum packaged or packaged in modified atmosphere, and stored at 10 °C, were monitored for 8 days as well as its sensory properties after boiling, frying, and baking.

2. MATERIAL AND METHODS

2.1 Raw materials

Potato tubers (*S. tuberosum* L.) of cv. Lady Claire (Dutch industrial potato cultivar) and Birgit (German table potato) were used. Both cultivars were grown in Croatia in the Slavonia region (45°40′N, 17°1′E) in 2016. During harvest and dark storage at 8 °C with approximately 100% relative humidity, potatoes were treated with an antisprouting agent (Gro Stop Basis and Gro Stop Fog, Certis Europe B.V., Great Abington, UK). Before transportation to the laboratory, potatoes were stored at 16 °C/3 days. For analysis purpose, samples were taken after 1, 5, and 9 months of storage. Uniform and undamaged tubers with a diameter greater than 35 mm were used. Potatoes were manually peeled with a sharp knife and washed with tap water.

2.2 Antibrowning treatment

Samples were cut into slices 4 mm in thickness with commercial cutting machine (MCM62020-CNCM30, Multitalent, Robert Bosch d.o.o., Škofja Loka, Slovenia) and dipped in solutions of sodium chloride (SC) (1%, w/v) (Solana d.d., Tuzla, Bosnia and Herzegovina) and sodium ascorbate (SA) (2%, w/v) (Nutrimedica d.o.o., Zagreb, Croatia) for 3 min at ambient temperature. Sample/solution (g/mL) ratio was 1:4. Slices were drained to reduce free water. Only uniform and undamaged slices were used for further preparation.

2.3 Packaging and storage conditions

After treatment with the antibrowning agent (ABA), samples (300 g) were packaged in a vacuum (VP) and modified atmosphere (MAP) (10.0% CO_2, 3.0% O_2, and 87.0% N_2) (Messer Croatia Plin d.o.o., Zagreb, Croatia) in polyamide/polyethylene (PA/PE) bags with film thickness 90 μm for VP (permeability at 23 °C and RH 0% for O_2 was 8.21 $cm^3/m^2/day/bar$) and PA/PE bags with film thickness 75 μm were used for MAP (permeability for O_2 was 22.3 $cm^3/m^2/day/bar$). VP was carried out using WS110W vacuum packager (Gorenje, Velenje, Slovenia), whereas Junior Digit device (Besser Vacuum, Dignano, Italy) was used for MAP.

Prepared samples ($n = 24$) were stored at 10 °C for 8 days and analyzed on the 0, second, fourth, and eighth storage day.

Whole preparation procedure and applied parameters were based on the results of a previous research, which is currently in the publishing process.

2.4 Monitoring the package gas composition

Gas content (%O_2 and CO_2) within the packages was measured by O_2/CO_2 analyzer (Oxybaby V O_2/CO_2, Witt-Gasetechnik, Witten, Germany). Instrument was calibrated with ambient air before the measurements. Samples were analyzed in triplicate ($n = 3$) and the results were expressed as mean ± standard error (SE).

2.5 Determination of weight loss, total solids, soluble solids, and pH

Prior to analysis, packaged samples were weighed before and during storage. Weight loss was calculated by subtraction potato mass before and after storage and expressed as % of initial mass.

In order to determine total solids (TS), soluble solids (SS), and pH, slices were crushed and homogenized with kitchen blender (CNHR9EV, Robert Bosch d.o.o., Škofja Loka, Slovenia). TS were determined by drying at 103 ± 2 °C to constant mass (AOAC, 1990), SS were measured by refractometer (PAL-1, Atago Co. Ltd., Tokyo, Japan), and pH value was determined using a pH meter (SevenEasy pH Meter S20, Mettler Toledo, Greifensee, Switzerland). All measurements were performed in triplicate ($n = 3$) and were expressed as mean ± SE.

2.6 Color analysis

Three slices of each sample were measured by a colorimeter (Spectrophotometer CM-3500d, Konica Minolta, Tokyo, Japan), which was calibrated with pure white (100% reflection) and black (0% reflection) standard. D65 light source with 2° angle observer, measuring plate with 30-mm diameter hole, and black cover were used. Color parameters L^*, a^*, and b^* were triple recorded for each slice ($n = 9$). All measurements were processed in Specular Component Excluded (SCE) mode, and parameters H° [$H^\circ = \arctan(b^*/a^*)$] and C^* [$C^* = (a^{*2} + b^{*2})^{1/2}$] were automatically calculated. Obtained results were expressed as mean ± SE.

2.7 Texture analysis

Texture analysis was performed on TA.HD.plus Texture Analyser (Stable Micro Systems, Godalming, UK) with 2-mm stainless-steel punch probe and 5-kg load cell. Pretest speed was 1 mm/s and test speed was adjusted to 0.5 mm/s. Textural parameters firmness (N), elasticity (mm), and work required for chewing (mJ) were calculated. Data were presented as mean ± SE of the triplicate test of three slices from each sample ($n = 9$).

2.8 Sensory monitoring

Sensory monitoring included a brief sensory evaluation of raw and cooked (boiled, fried, and baked) FCP samples. For boiled samples, 100 g of slices were boiled in 500 mL of distilled water at 100 °C/15 min and drained. For fried FCP samples, slices (180 g) were fried in 1.5 L sunflower oil (Zvijezda plus d.o.o., Zagreb, Croatia) at 180 °C/5 min and put on a paper towel for oil absorption. Also, slices (120 g) were put on a baking paper, overflowed with 6 mL of sunflower oil, and baked in an oven at 220 °C/30 min. After cooling at ambient temperature, samples of raw and cooked FCP were served on plastic-coated plates and sensory evaluated (Aguayo, Escalona, & Artés, 2006; Dite Hunjek et al., 2020; Levaj, Bunić, Dragović-Uzelac, & Kovačević, 2010; Putnik et al., 2017) by a trained panel of five people ($n = 5$) from the faculty staff and students (five females, 24 to 58 years aged) using Quantitative Descriptive Analysis (QDA) by scale 1 to 5. Prior evaluation, panelists took a 2-hr training session in order to get acquainted with the product and to define related sensory descriptors. The procedure was performed according to the guidelines ISO 8586 (ISO, 2012) and ISO 6564 (ISO, 1985) in individual sensory booths under cool white fluorescent light in a sensory laboratory equipped according to ISO 8589 (ISO, 2007) at ambient room temperature (20 °C) with a questionnaire that included descriptors previously described by Dite Hunjek et al. (2020). Briefly, color, as the intensity of browning, was graded with 1 = *no browning* (characteristic potato color) to 5 = *complete browning*. The intensity of characteristic odor and off-odor was scored with 1 = *absent* to 5 = *very pronounced*. Moistness and firmness of raw potatoes were tested by pressing the slices between the thumb and point finger, whereas cooked ones by chewing, and scored from 1 = *very soft and dry* to 5 = *very firm and wet*. Additionally, creaminess of boiled samples was assessed where 1 = *absence of creamy texture* and 5 = *melting in the mouth*. Characteristic, sweet, sour, salty, bitter, and off-taste were evaluated in all cooked samples (1 = *absent* to 5 = *very pronounced*), whereas attributes of oiliness and crispness were evaluated only in fried and baked samples (1 = *absent* to 5 = *very pronounced*). All sensory data were presented as mean ± SE.

2.9 Statistical analysis

Statistical analysis was conducted using Statistica version 8.0 software (Statsoft Inc., Tulsa, OK, USA). Full factorial randomized experimental design was used and basic information about the experimental dataset was assessed by the descriptive statistic. Dependent continuous variables were as follows: O_2 and CO_2 content (%), weight loss (%), TS (%), SS (%), pH, L^*, a^*, b^*, C^*, H°, firmness (N), elasticity (mm), work (mJ), and 14 sensory attributes. Independent categorical variables were as follows: (a) cultivars (Birgit and Lady Claire), (b) tubers' age (1, 5, and 9 months), (c) ABA (SC [1%] and SA [2%]), (d) package atmosphere (VP and MAP), (f) storage time (0, second, fourth, and eighth day). Continuous variables were analyzed by multivariate analysis of variance and marginal mean values were compared with the Tukey's HSD test. Possible grouping of raw and cooked samples was tested using principal component analysis (PCA). The significance level for all tests was $P \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Package gas composition

All investigated sources of variation significantly affected O_2 and CO_2 levels in packaged FCP (Table 1). Samples of cv. Birgit accumulated less O_2 and more CO_2 than cv. Lady Claire samples. These results indicate increased respiration of cv. Birgit, what can be attributed to cultivar characteristic. Cv. Birgit is a table potato, whereas cv. Lady Claire is an industrial potato suitable for longer storage period (European Cultivated Potato Database [ECPD]: https://www.europotato.org/). Differences in respiration rate among different cultivars also occurred in researches by Silveira, Oyarzún, Sepúlveda, and Escalona (2017) and Broćić, Dolijanović, Poštić, Milošević, and Savić (2016) as a consequence of metabolic behavior.

Tubers' age showed a significant influence ($P \leq 0.05$) on O_2 and CO_2 level in FCP bags, where the lowest O_2 and highest CO_2 levels were recorded in FCP bags produced from the fifth months of tubers' age. However, those differences were numerically negligible, especially in the CO_2 level. Silveira et al. (2017) observed that the respiration rate became lower with tubers' aging because immediately after harvesting potatoes have the highest respiration rate due to removal from the soil and applied mechanization. Wustman and Struik (2007) indicated that increase of respiration rate during fifth month of storage is most likely due to potatoes tendency for germination during that period. Such a phenomenon is not obvious in FCP produced from tubers of different age probably due to peeling and cutting, which itself accelerate respiration (Limbo & Piergiovanni, 2006).

FCP treated with SA had a higher level of O_2 and lower CO_2 level than SC-treated samples, which implicates slower respiration of SA-treated slices. Similarly, Limbo and Piergiovanni (2006) noticed that ascorbic acid could reduce respiration rate probably due to inhibition of not only the polyphenol oxidase activity but also enzymes of the oxidative phosphorylation pathway.

VP samples had higher O_2 level and lower CO_2 level than MAP samples due to initial gas composition used for MAP as well as the permeability of packaging film, where MAP bag attributed with higher permeability for O_2 than VP bags.

During FCP storage, the level of O_2 was inversely proportional to CO_2 level as well as the depletion of O_2 and CO_2 releasing was the highest on the beginning of storage until some kind of equilibrium was established during storage.

3.2 Weight loss, TS, SS, and pH

Among all examined sources of variation, significant impact ($P \leq 0.05$) on weight loss of FCP samples had only tubers' age and storage time (Table 1). Tubers are more susceptible to weight loss at the beginning of storage (Broćić et al., 2016) as well at the end, when the dormancy period usually could be broken (Suttle, 2004). Such a phenomenon could explain higher FCP weight loss at first and ninth month than at fifth month tubers' storage. Further, Rocha, Coulon, and Morais (2003) recorded a similar percentage of FCP weight loss in VP samples stored for 7 days as it was in the present study. FCP samples weight loss in this study ranged from 2.28% at the second day to 1.57% at the eighth day of storage and probably was caused by respiration as indicated by an inverse trend of O_2 level.

Contrary to weight loss, all investigated sources of variation significantly affected TS and SS of examined samples ($P \leq 0.05$), except for combinations of tubers' age × ABA and package atmosphere on SS, where significance was absent ($P > 0.05$) (Table 1).

Cv. Birgit showed lower TS (18.45%) and SS (5.77%) compared to cv. Lady Claire (TS = 24.21% and SS = 6.52%). According to the ECPD data, cv. Lady Claire dry matter is higher in comparison with other cultivars, whereas cv. Birgit dry matter is at the middle level. During higher tubers' age and FCP storage time,

Table 1–Influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on physical and chemical parameters of raw fresh-cut potato.

Source of variation	O_2 (%)	CO_2 (%)	Weight loss (%)	Total solids (%)	Soluble solids (%)	pH
Cultivar	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.88$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$
B	7.84 ± 0.23^a	8.12 ± 0.16^b	1.67 ± 0.003^a	18.45 ± 0.08^a	5.77 ± 0.04^a	5.97 ± 0.01^a
LC	9.07 ± 0.23^b	7.35 ± 0.16^a	1.64 ± 0.003^a	24.21 ± 0.08^b	6.52 ± 0.04^b	6.04 ± 0.01^b
Tubers' age (month)	$P \leq 0.01^*$	$P = 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.01^*$
1	8.91 ± 0.28^b	7.67 ± 0.19^{ab}	2.08 ± 0.004^a	22.14 ± 0.09^b	5.53 ± 0.05^a	6.02 ± 0.01^b
5	7.29 ± 0.28^a	8.11 ± 0.19^b	0.84 ± 0.004^b	20.87 ± 0.09^a	5.98 ± 0.05^b	6.02 ± 0.01^b
9	9.18 ± 0.28^b	7.43 ± 0.19^a	2.05 ± 0.004^a	20.98 ± 0.09^a	6.93 ± 0.05^c	5.98 ± 0.01^a
ABA	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.36$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$
SC	7.92 ± 0.23^a	8.12 ± 0.16^b	1.77 ± 0.003^a	20.88 ± 0.08^a	6.02 ± 0.04^a	5.98 ± 0.01^a
SA	9.00 ± 0.23^b	7.35 ± 0.16^a	1.54 ± 0003^a	21.78 ± 0.08^b	6.28 ± 0.04^b	6.03 ± 0.01^b
Package atmosphere	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.30$	$P \leq 0.01^*$	$P = 0.18$	$P \leq 0.01^*$
VP	14.48 ± 0.23^b	5.69 ± 0.16^a	1.52 ± 0.003^a	21.64 ± 0.08^b	6.19 ± 0.04^a	5.93 ± 0.01^a
MAP	2.44 ± 0.23^a	9.78 ± 0.16^b	1.78 ± 0.003^a	21.02 ± 0.08^a	6.10 ± 0.04^a	6.09 ± 0.01^b
Storage time (day)	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$
0	11.88 ± 0.32^c	5.40 ± 0.22^a	0.00 ± 0.006^c	22.75 ± 0.11^c	6.00 ± 0.06^a	6.23 ± 0.01^d
2	6.63 ± 0.32^a	9.89 ± 0.22^d	2.28 ± 0.006^{ab}	20.61 ± 0.11^a	5.92 ± 0.06^a	6.02 ± 0.01^c
4	5.86 ± 0.32^a	8.47 ± 0.22^c	2.76 ± 0.006^a	21.10 ± 0.11^b	6.37 ± 0.06^b	5.92 ± 0.01^b
8	9.47 ± 0.32^b	7.18 ± 0.22^b	1.57 ± 0.006^b	20.86 ± 0.11^{ab}	6.30 ± 0.06^b	5.87 ± 0.01^a
Cultivar × tubers' age (month)	$P \leq 0.01^*$	$P = 0.13$	$P = 0.08$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.08$
B × 1	8.97 ± 0.40^b	8.17 ± 0.27^a	2.31 ± 0.007^a	19.52 ± 0.13^b	5.25 ± 0.08^a	5.97 ± 0.02^a
B × 5	6.98 ± 0.40^a	8.18 ± 0.27^a	0.46 ± 0.007^a	18.01 ± 0.13^a	5.74 ± 0.08^b	5.99 ± 0.02^a
B × 9	7.58 ± 0.40^{ab}	8.01 ± 0.27^a	2.25 ± 0.007^a	17.82 ± 0.13^a	6.32 ± 0.08^c	5.96 ± 0.02^a
LC × 1	8.85 ± 0.40^b	7.17 ± 0.27^a	1.84 ± 0.007^a	24.76 ± 0.13^d	5.81 ± 0.08^b	6.07 ± 0.02^a
LC × 5	7.60 ± 0.40^{ab}	8.04 ± 0.27^a	1.22 ± 0.007^a	23.74 ± 0.13^c	6.22 ± 0.08^c	6.05 ± 0.02^a
LC × 9	10.78 ± 0.40^c	6.85 ± 0.27^a	1.84 ± 0.007^a	24.14 ± 0.13^c	7.53 ± 0.08^d	6.00 ± 0.02^a
Tubers' age (month) × ABA	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.06$	$P = 0.14$	$P = 0.78$	$P \leq 0.01^*$
1 × SC	7.13 ± 0.40^a	8.88 ± 0.27^c	2.21 ± 0.007	21.55 ± 0.13^a	5.38 ± 0.08^a	5.98 ± 0.02^a
1 × SA	10.68 ± 0.40^b	6.46 ± 0.27^a	1.95 ± 0.007^a	22.73 ± 0.13^a	5.68 ± 0.08^a	6.06 ± 0.02^b
5 × SC	7.35 ± 0.40^a	7.90 ± 0.27^{bc}	0.58 ± 0.007^a	20.43 ± 0.13^a	5.88 ± 0.08^a	5.97 ± 0.02^a
5 × SA	7.23 ± 0.40^a	8.31 ± 0.27^{bc}	1.09 ± 0.007^a	21.32 ± 0.13^a	6.08 ± 0.08^a	6.07 ± 0.02^b
9 × SC	9.27 ± 0.40^b	7.59 ± 0.27^b	2.52 ± 0.007^a	20.65 ± 0.13^a	6.79 ± 0.08^a	5.98 ± 0.02^a
9 × SA	9.08 ± 0.40^b	7.28 ± 0.27^{ab}	1.57 ± 0.007^a	21.31 ± 0.13^a	7.07 ± 0.08^a	5.97 ± 0.02^a
Grand mean	8.46	7.74	1.65	21.33	6.15	6.01

Note. Results are expressed as mean ± SE.
Abbreviations: B, Birgit; LC, Lady Claire; ABA, antibrowning agent; SC, sodium chloride (1%); SA, sodium ascorbate (2%); VP, vacuum packaging; MAP, modified atmosphere packaging.
*Statistically significant variable at $P \leq 0.05$. Values with different letters are statistically different at $P \leq 0.05$.

TS decreased probably due to starch degradation (Wustman & Struik, 2007). Further, starch decomposition into soluble sugars (Saha, Gupta, & Tyagi, 2014) could lead to SS increase, which was recorded in Ierna, Rizzarelli, Malvuccio, and Rapisarda (2017) study as well in this study. Kaul et al. (2010) researched biochemical behavior of potato cultivars in controlled conditions storage during 210 days and found that tubers' dry matter increased during storage because of the evaporation and respiration, but in that study dry matter was not determined during FCP processing and storage. Peeling and cutting damage potato tissue and cells and consequently dry matter losses could appear more in older potato.

TS was higher in SA-treated samples than in samples treated with SC (Table 1). Also, TS was higher in VP samples compared to MAP samples, although the difference was very slight. This showed that SA and VP better preserved samples stability and better prevented degradation of macromolecules such as starch (Saha et al., 2014) and slightly lower respiration could possibly contribute to better stability. Packaging type did not show significant differences among samples SS content.

All investigated sources of variation significantly affected the pH of examined samples ($P \leq 0.05$) and values ranged from 5.92 to 6.23, except combinations of cultivar × tubers' age, where significance was absent ($P > 0.05$) (Table 1).

Slight pH decrease was observed after 5 months of tubers' storage. Storage time of FCP samples caused pH decrease from 6.23 to 5.87 probably as a consequence of gas composition in packages, especially in CO_2 level (Soliva-Fortuny, Grigelmo-Miguel, Hernando, Lluch, & Martín-Belloso, 2002), which increased during storage. The same results were also recorded in the Rocha et al.'s (2003) research. Samples treated with SC had negligible lower pH (5.93) than samples treated with SA (6.03), which could also be more likely linked to CO_2 level than to ABA impact due to pretty similar pH of used ABA. However, in the case of acidic ABA application higher concentration of ABA solution could cause lower pH of samples (Calder, Kash, Davis-Dentici, & Bushway, 2011). Additionally, higher O_2 level was measured in VP samples what could contribute to higher respiration and other physiological processes and thereby could result with slightly lower pH.

3.3 Color analysis

Generally, all investigated sources of variation significantly affected all color parameters of examined samples ($P \leq 0.05$). Significance was absent ($P > 0.05$) in the influence of ABA on b^* and C^*, storage time on a^* and H°, combinations of cultivar × tubers' age on L^* and a^* as well as tubers' age × ABA on all color parameters (Table 2).

Table 2–Influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on color and texture properties of raw fresh-cut potato.

Source of variation	L^*	a^*	b^*	C^*	H°	Firmness (N)	Elasticity (mm)	Work (mJ)
Cultivar	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.17$
B	70.05 ± 0.15^b	1.56 ± 0.05^b	41.08 ± 0.19^b	41.12 ± 0.19^b	87.83 ± 0.08^a	7.42 ± 0.08^a	2.10 ± 0.03^a	2.93 ± 0.04^a
LC	69.32 ± 0.15^a	-0.01 ± 0.05^a	31.86 ± 0.19^a	31.88 ± 0.19^a	90.05 ± 0.08^b	7.99 ± 0.08^b	2.43 ± 0.03^b	2.85 ± 0.04^a
Tubers' age (month)	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$
1	70.10 ± 0.18^b	0.54 ± 0.06^a	35.72 ± 0.23^a	35.75 ± 0.23^a	89.29 ± 0.10^b	7.25 ± 0.10^a	1.85 ± 0.04^a	1.60 ± 0.05^a
5	70.08 ± 0.18^b	0.55 ± 0.06^a	37.03 ± 0.23^b	37.05 ± 0.23^b	89.37 ± 0.10^b	7.74 ± 0.10^b	2.34 ± 0.04^b	3.31 ± 0.05^b
9	68.87 ± 0.18^a	1.24 ± 0.06^b	36.66 ± 0.23^b	36.70 ± 0.23^b	88.15 ± 0.10^a	8.13 ± 0.10^c	2.62 ± 0.04^c	3.75 ± 0.05^c
ABA	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.07$	$P = 0.07$	$P \leq 0.01^*$	$P = 0.65$	$P = 0.40$	$P = 0.29$
SC	69.13 ± 0.15^a	0.89 ± 0.05^b	36.22 ± 0.19^a	36.25 ± 0.19^a	88.76 ± 0.08^a	7.68 ± 0.08^a	2.25 ± 0.03^a	2.86 ± 0.04^a
SA	70.25 ± 0.15^b	0.66 ± 0.05^a	36.72 ± 0.19^a	36.74 ± 0.19^a	89.11 ± 0.08^b	7.73 ± 0.08^a	2.29 ± 0.03^a	2.92 ± 0.04^a
Package atmosphere	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.35$	$P = 0.56$	$P = 0.62$
VP	70.29 ± 0.15^b	0.53 ± 0.05^a	36.96 ± 0.19^b	36.98 ± 0.19^b	89.36 ± 0.08^b	7.76 ± 0.08^a	2.25 ± 0.03^a	2.87 ± 0.04^a
MAP	69.09 ± 0.15^a	1.02 ± 0.05^b	35.98 ± 0.19^a	36.01 ± 0.19^a	88.51 ± 0.08^a	7.65 ± 0.08^a	2.28 ± 0.03^a	2.90 ± 0.04^a
Storage time (day)	$P \leq 0.01^*$	$P = 0.04^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.03^*$	$P = 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$
0	70.82 ± 0.21^c	0.72 ± 0.07^{ab}	38.63 ± 0.27^c	38.65 ± 0.27^c	89.03 ± 0.12^{ab}	8.03 ± 0.12^b	2.05 ± 0.04^a	2.46 ± 0.06^a
2	70.15 ± 0.21^{bc}	0.67 ± 0.07^a	36.40 ± 0.27^b	36.43 ± 0.27^b	89.13 ± 0.12^b	7.53 ± 0.12^a	2.33 ± 0.04^b	3.05 ± 0.06^b
4	69.52 ± 0.21^b	0.95 ± 0.07^b	36.29 ± 0.27^b	36.33 ± 0.27^b	88.67 ± 0.12^a	7.74 ± 0.12^{ab}	2.29 ± 0.04^b	3.12 ± 0.06^b
8	68.25 ± 0.21^a	0.77 ± 0.07^{ab}	34.56 ± 0.27^a	34.59 ± 0.27^a	88.91 ± 0.12^{ab}	7.52 ± 0.12^a	2.39 ± 0.04^b	2.93 ± 0.06^b
Cultivar × tubers' age (month)	$P = 0.11$	$P = 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P \leq 0.01^*$	$P = 0.16$	$P \leq 0.01^*$	$P = 0.59$
B × 1	70.27 ± 0.26^a	1.33 ± 0.09^c	40.74 ± 0.33^c	40.79 ± 0.33^c	88.13 ± 0.14^b	7.07 ± 0.14^a	1.81 ± 0.05^a	1.60 ± 0.07^a
B × 5	70.33 ± 0.26^a	1.46 ± 0.09^c	42.36 ± 0.33^d	42.39 ± 0.33^d	88.03 ± 0.14^b	7.50 ± 0.14^a	2.19 ± 0.05^b	3.36 ± 0.07^a
B × 9	69.55 ± 0.26^a	1.89 ± 0.09^d	40.13 ± 0.33^c	40.18 ± 0.33^c	87.31 ± 0.14^a	7.69 ± 0.14^a	2.31 ± 0.05^{bc}	3.83 ± 0.07^a
LC × 1	69.94 ± 0.26^a	-0.26 ± 0.09^a	30.70 ± 0.33^a	30.71 ± 0.33^a	90.44 ± 0.14^d	7.43 ± 0.14^a	1.89 ± 0.05^a	1.60 ± 0.07^a
LC × 5	69.84 ± 0.26^a	-0.36 ± 0.09^a	31.69 ± 0.33^a	31.70 ± 0.33^a	90.71 ± 0.14^d	7.97 ± 0.14^a	2.48 ± 0.05^c	3.26 ± 0.07^a
LC × 9	68.19 ± 0.26^a	0.60 ± 0.09^b	33.19 ± 0.33^b	33.21 ± 0.33^b	88.99 ± 0.14^c	8.57 ± 0.14^a	2.93 ± 0.05^d	3.68 ± 0.07^a
Tubers' age (month) × ABA	$P = 0.31$	$P = 0.41$	$P = 0.39$	$P = 0.38$	$P = 0.50$	$P = 0.66$	$P = 0.22$	$P = 0.14$
1 × SC	69.34 ± 0.26^a	0.70 ± 0.09^a	35.23 ± 0.33^a	35.26 ± 0.33^a	89.05 ± 0.14^a	7.19 ± 0.14^a	1.88 ± 0.05^a	1.51 ± 0.07^a
1 × SA	70.86 ± 0.26^a	0.37 ± 0.09^a	36.21 ± 0.33^a	36.24 ± 0.33^a	89.53 ± 0.14^a	7.31 ± 0.14^a	1.81 ± 0.05^a	1.69 ± 0.07^a
5 × SC	69.73 ± 0.26^a	0.68 ± 0.09^a	36.98 ± 0.33^a	37.01 ± 0.33^a	89.17 ± 0.14^a	7.78 ± 0.14^a	2.30 ± 0.05^a	3.36 ± 0.07^a
5 × SA	70.44 ± 0.26^a	0.42 ± 0.09^a	37.07 ± 0.33^a	37.09 ± 0.33^a	89.57 ± 0.14^a	7.69 ± 0.14^a	2.37 ± 0.05^a	3.26 ± 0.07^a
9 × SC	68.31 ± 0.26^a	1.30 ± 0.09^a	36.46 ± 0.33^a	36.49 ± 0.33^a	88.07 ± 0.14^a	8.06 ± 0.14^a	2.56 ± 0.05^a	3.69 ± 0.07^a
9 × SA	69.44 ± 0.26^a	1.19 ± 0.09^a	36.87 ± 0.33^a	36.90 ± 0.33^a	88.23 ± 0.14^a	8.19 ± 0.14^a	2.67 ± 0.05^a	3.81 ± 0.07^a
Grand mean	69.69	0.78	36.47	36.50	88.94	7.70	2.27	2.89

Note. Results are expressed as mean ± SE.
Abbreviations: B, Birgit; LC, Lady Claire; ABA, antibrowning agent; SC, sodium chloride (1%); SA, sodium ascorbate (2%); VP, vacuum packaging; MAP, modified atmosphere packaging.
*Statistically significant variable at $P \leq 0.05$. Values with different letters are statistically different at $P \leq 0.05$.

All color parameters except H° were higher in cv. Birgit samples in comparison with cv. Lady Claire. The highest difference between cultivars was observed in b^* and C^* values, which generally means that cv. Birgit was more vivid and located within the more yellow part of the color spectrum what is in accordance with ECPD, where cv. Birgit is described as a yellow cultivar. Cornacchia et al. (2011) supported such observations about certain color differences among various cultivars.

Tubers' aging decreased L^*, showing that the color of FCP became darker and implicated that older tubers were more susceptible to browning. Values of a^*, b^*, and C^* increased and H° decreased in older tubers, which means that FCP color altered but still was in the yellow spectrum (a^* was very low [1.59] and H° was still pretty close to $+b^*$ axis [yellow]). Similar results were recorded in Silveira et al.'s (2017) research, where storage time (2 and 4 months) of various potato cultivars showed the same impact on color parameters (decreasing of L^* and H°) as in the present study.

ABA showed a significant influence ($P \leq 0.05$) only on L^*, a^*, and H° (Table 2). Samples treated with SA had higher L^* and H° and lower a^* compared to the samples treated with SC, meaning that SA-treated samples were brighter compared to samples treated with SC. Sodium ascorbate is a mineral salt of ascorbic acid and is well known antioxidant approved for use as a food additive (European Regulation [EC] No. 1333/2008 [European Commission, 2008] and 1129/2011 [European Commission, 2011]). SA, as the reducing agent, reacts with quinone and converts it back to phenols, removes oxygen from reactions with polyphenol oxidase, and is the chelate agent that causes less enzyme activity (Marshall, Kim, & Wei, 2000) and thus being successful ABA (Li et al., 2017; Limbo & Piergiovanni, 2006; Rocculi et al., 2007). Sodium chloride inactivates enzyme polyphenol oxidase (Marshall et al., 2000) and its antibrowning effect has been explored on apples (Lu, Luo, Turner, & Feng, 2007; Son, Moon, & Lee, 2001), but SC would probably be more effective on potato in synergy with some other ABA.

Considering the package atmosphere type, its significant influence ($P \leq 0.05$) on all color parameters was observed (Table 2). However, differences in samples color between these two types of packaging were numerically inconsiderable. Increased CO_2

concentrations were present in both types of packaging, which could disable the function of some enzymes in the Krebs cycle (Kader, 1986; Rocculi, Romani, Gómez Galindo, & Dalla Rosa, 2009) and prolong shelf life (Gorris & Peppelenbos, 1992). In this study, gas composition of VP samples (CO_2 = 5.69% and O_2 = 14.48%) seems to be more preferable for color protection from enzymatic browning than MAP, where CO_2 was higher (9.78%) and O_2 lower (2.44%). Such gas composition in MAP, almost anaerobic, possibly caused such a slight difference in color between those two packaging types.

Parameters L^*, b^*, and C^* decreased during storage, but generally, it was observed only at the end of storage. Cornacchia et al. (2011) examined potato browning of cv. Ariana, Liseta, Safrane, and Spunta stored at 5 °C/8 days and 20 °C/6 days, where they observed L^* decreasing in all cultivars and other parameters' changes differed by cultivars. Gao, Zeng, Ren, Li, and Xu (2018) recorded a decrease of L^* and increase of a^* with no significant differences in b^* in potato samples treated with γ-aminobutyric acid and analyzed during storage at 4 °C/6 days.

3.4 Texture analysis

The influence of investigated sources of variation on texture parameters is given in Table 2, where it can be seen that cultivar type significantly ($P \leq 0.05$) affected firmness and elasticity, tubers' age all texture parameters, storage time elasticity and work, and combinations of cultivar × tubers' age elasticity.

Cv. Lady Claire showed more firmness (7.99N) and higher elasticity (2.43 mm) in comparison with cv. Birgit (firmness = 7.42N; elasticity = 2.10 mm). Such texture results correspond with SS results, which are in accordance with results in Ierna et al. (2017) study.

With tubers' aging, all analyzed parameters increased. Potatoes could become firmer over time due to cross-linking of cell wall components and suberin deposition, so-called wounding response, and water loss (Rocculi et al., 2009), although water loss was not noticed in our study. Furthermore, elasticity slightly increased with aging and is more highlighted in cv. Lady Claire.

Considering storage time, significant impact for FCP firmness was absent ($P > 0.05$), whereas significant increase of elasticity and work ($P \leq 0.05$) was observed only in first two storage days after which they remained pretty stable.

3.5 Sensory monitoring

Widely used potatoes' cooking methods are boiling, frying, and baking, among which frying is the most popular (Dourado et al., 2019). During frying surface porosity, shrinkage and roughness increase forming desirable texture, as well as characteristic color and aroma profile are developed as a result of Maillard reactions (Miranda & Aguilera, 2006). The overall quality of fried or baked potato is a combination of sensory perception of appearance, texture, taste, and overall consumer acceptability. In general, and particularly for fried potatoes prepared from FCP, their quality depends on the quality of used tubers (e.g., influenced by cultivar and aging) and applied manufacturing process (among others cutting, ABA treatment, packaging). Considering that consumers choose FCP based on visual appearance, it was necessary to conduct sensory monitoring of raw FCP along with cooked ones (boiled, fried, and baked) to complete an insight in sensory acceptability of investigated FCP.

3.5.1 Raw samples. Results of sensory monitoring's statistical analysis of raw FCP are presented in Table 3. Each source of variation had a significant impact ($P \leq 0.05$) on several sensory attributes, but all of them significantly affected color in terms of browning.

Cultivar type showed significant influence ($P \leq 0.05$) on color and off-odor. Color of cv. Birgit (scored with 1.4) was evaluated as brighter than color of cv. Lady Claire (scored with 2.8). This was in accordance with instrumentally obtained color results (Table 1). Off-odor was slightly more recognized in the cv. Lady Claire samples (1.9) than in cv. Birgit (1.7).

Tubers' age had a significant influence ($P \leq 0.05$) on color, off-odor, moistness, and firmness (Table 3). During tubers' aging, FCP color became darker most likely due to cell wall degradation caused by aging (Jansky, 2010) mutually with FCP processing operations allowing the interaction of polyphenol oxidase with oxygen, which leads to browning (Whitaker & Lee, 1995). There was no correspondence between FCP off-odor and tubers' aging and lower FCP off-odor was detected after the fifth month of storage. Moistness and firmness of FCP changed in the first half of tubers' storage and later became stable, where they showed the opposite trend: moistness increased as firmness decreased. As previously discussed, instrumentally measured firmness values (Table 2) showed an inverse tendency during tubers' aging compared to sensorially evaluated firmness, which could be a consequence of various methods principle (puncture and palpation, respectively).

ABA showed a significant influence ($P \leq 0.05$) on color and characteristic odor. Slices treated with SA were less brown (2.0) than ones treated with SC (2.2), which proves that SA more effectively prevents the enzymatic browning and corresponds with instrumentally measured color parameters. Characteristic odor was more pronounced in SA-treated samples.

Package atmosphere significantly ($P \leq 0.05$) affected all examined sensory properties, except firmness, which is similar to the trend of instrumentally measured values (Table 2). MAP samples were scored darker (2.2) than VP samples (2.0). Also, MAP samples had less pronounced characteristic odor and moistness than VP ones (Beltran, Selma, Tudela, & Gil, 2005).

Storage time of FCP had a significant influence ($P \leq 0.05$) on all sensory parameters, where browning was more obvious with storage time, the characteristic odor became less pronounced opposite to off-odor, which became more perceptible. Thybo, Christiansen, Kaack, and Petersen (2006) and Arvanitoyannis, Vaitsi, and Mavromatis (2008) also confirmed off-odor increasing during FCP storage. Methoxypyrazines are linked to undesirable flavor compounds, detectable in very low concentrations with high aroma impact (Duckham, Dodson, Bakker, & Ames, 2002), derived from amino acids present in raw potato and its increase could be caused by cell damage during peeling and cutting (Jansky, 2010). Firmness became less pronounced, which is again consistent with the texture analysis results, as well as moistness. Their changes were stronger noticed in the first days of storage but later remained pretty stable.

3.5.2 Boiled samples. After certain storage days, FCP was boiled and sensory evaluated in order to have a better insight in sensory properties of boiled FCP affected by examined sources of variation (Table 4).

Again, cultivar type had a significant influence ($P \leq 0.05$) on color, moistness, creaminess, characteristic taste, and off-taste. Cv. Birgit was scored as brighter with more moistness and creaminess, characteristic taste, and less off-taste.

Tubers' age had a significant influence ($P \leq 0.05$) on color, moistness, creaminess, characteristic taste, sour, salty, bitter, and off-taste but changes of those attributes, with the exception of

Table 3–Influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on sensory properties of raw fresh-cut potato.

Source of variation	Color (Browning)	Characteristic odor	Off-odor	Moistness	Firmness
Cultivar	$P \leq 0.01^{*}$	$P = 0.22$	$P = 0.05^{*}$	$P = 0.25$	$P = 0.45$
B	1.4 ± 0.0^{a}	3.2 ± 0.1^{a}	1.7 ± 0.0^{a}	3.1 ± 0.1^{a}	4.0 ± 0.1^{a}
LC	2.8 ± 0.0^{b}	3.0 ± 0.1^{a}	1.9 ± 0.0^{b}	3.0 ± 0.1^{a}	3.9 ± 0.1^{a}
Tubers' age (month)	$P \leq 0.01^{*}$	$P = 0.18$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$
1	1.9 ± 0.1^{a}	2.9 ± 0.1^{a}	2.0 ± 0.1^{b}	2.8 ± 0.1^{a}	4.2 ± 0.1^{b}
5	2.1 ± 0.1^{b}	3.2 ± 0.1^{a}	1.5 ± 0.1^{a}	3.2 ± 0.1^{b}	3.8 ± 0.1^{a}
9	2.3 ± 0.1^{c}	3.2 ± 0.1^{a}	1.9 ± 0.1^{b}	3.2 ± 0.1^{b}	3.8 ± 0.1^{a}
ABA	$P \leq 0.01^{*}$	$P = 0.04^{*}$	$P = 0.12$	$P = 0.09$	$P = 0.73$
SC	2.2 ± 0.0^{b}	3.0 ± 0.1^{a}	1.7 ± 0.0^{a}	3.1 ± 0.1^{a}	3.9 ± 0.1^{a}
SA	2.0 ± 0.0^{a}	3.2 ± 0.1^{b}	1.8 ± 0.0^{a}	2.9 ± 0.1^{a}	3.9 ± 0.1^{a}
Package atmosphere	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P = 0.81$
VP	2.0 ± 0.0^{a}	3.3 ± 0.1^{b}	1.7 ± 0.0^{b}	3.2 ± 0.1^{b}	3.9 ± 0.1^{a}
MAP	2.2 ± 0.0^{b}	2.9 ± 0.1^{a}	1.9 ± 0.0^{a}	2.9 ± 0.1^{a}	3.9 ± 0.1^{a}
Storage time (day)	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$
0	1.2 ± 0.1^{a}	3.5 ± 0.1^{b}	1.3 ± 0.1^{a}	3.4 ± 0.1^{b}	4.3 ± 0.1^{b}
2	2.3 ± 0.1^{b}	3.1 ± 0.1^{b}	1.5 ± 0.1^{ab}	2.8 ± 0.1^{a}	3.9 ± 0.1^{a}
4	2.4 ± 0.1^{b}	3.2 ± 0.1^{b}	1.7 ± 0.1^{b}	3.1 ± 0.1^{ab}	3.8 ± 0.1^{a}
8	2.5 ± 0.1^{b}	2.6 ± 0.1^{a}	2.5 ± 0.1^{c}	2.8 ± 0.1^{a}	3.7 ± 0.1^{a}
Cultivar × tubers' age (month)	$P = 0.02^{*}$	$P = 0.96$	$P = 0.03^{*}$	$P = 0.99$	$P = 0.71$
B × 1	1.2 ± 0.1^{a}	3.0 ± 0.1^{a}	2.0 ± 0.1^{c}	2.8 ± 0.1^{a}	4.2 ± 0.1^{a}
B × 5	1.4 ± 0.1^{a}	3.3 ± 0.1^{a}	1.4 ± 0.1^{a}	3.2 ± 0.1^{a}	3.8 ± 0.1^{a}
B × 9	1.5 ± 0.1^{a}	3.2 ± 0.1^{a}	1.8 ± 0.1^{bc}	3.2 ± 0.1^{a}	3.8 ± 0.1^{a}
LC × 1	2.6 ± 0.1^{b}	2.9 ± 0.1^{a}	1.9 ± 0.1^{c}	2.7 ± 0.1^{a}	4.2 ± 0.1^{a}
LC × 5	2.8 ± 0.1^{b}	3.1 ± 0.1^{a}	1.6 ± 0.1^{ab}	3.1 ± 0.1^{a}	3.7 ± 0.1^{a}
LC × 9	3.2 ± 0.1^{c}	3.1 ± 0.1^{a}	2.0 ± 0.1^{c}	3.1 ± 0.1^{a}	3.8 ± 0.1^{a}
Tubers' age (month) × antibrowning agent	$P = 0.07$	$P = 0.53$	$P = 0.01^{*}$	$P = 0.64$	$P = 0.19$
1 × SC	1.9 ± 0.1^{a}	2.7 ± 0.2^{a}	1.8 ± 0.1^{bc}	2.9 ± 0.1^{a}	4.1 ± 0.1^{a}
1 × SA	1.9 ± 0.1^{a}	3.1 ± 0.1^{a}	2.1 ± 0.1^{d}	2.6 ± 0.1^{a}	4.3 ± 0.1^{a}
5 × SC	2.2 ± 0.1^{a}	3.1 ± 0.2^{a}	1.6 ± 0.1^{ab}	3.2 ± 0.1^{a}	3.8 ± 0.1^{a}
5 × SA	2.0 ± 0.1^{a}	3.3 ± 0.2^{a}	1.4 ± 0.1^{a}	3.1 ± 0.1^{a}	3.7 ± 0.1^{a}
9 × SC	2.5 ± 0.2^{a}	3.1 ± 0.1^{a}	1.9 ± 0.1^{cd}	3.2 ± 0.1^{a}	3.9 ± 0.1^{a}
9 × SA	2.2 ± 0.1^{a}	3.2 ± 0.1^{a}	1.9 ± 0.1^{cd}	3.1 ± 0.1^{a}	3.7 ± 0.1^{a}
Grand mean	2.1	3.1	1.8	3.0	3.9

Note. Results are expressed as mean ± SE.
Abbreviations: B, Birgit; LC, Lady Claire; ABA, antibrowning agent; SC, sodium chloride (1%); SA, sodium ascorbate (2%); VP, vacuum packaging; MAP, modified atmosphere packaging.
[*]Statistically significant variable at $P \leq 0.05$. Values with different letters are statistically different at $P \leq 0.05$.

creaminess, were recorded only at the latest storage months and numerically were not remarkable. On the ninth month of tubers' aging, boiled FCP was attributed with lower scores for desirable and higher scores for undesirable properties than samples from the earlier aging period. Browning was very slight, creaminess decreased as well as characteristic taste, whereas scores for sour, salty, bitter, and off-taste increased. Boiled FCP had more pronounced characteristic odor than raw FCP and off-odor was inversely scored. Potato contains 5′ ribonucleotides, compounds responsible for flavor intensity as flavor potentiators, which are releasing during thermal treatment by enzymatic hydrolysis of RNA and in reactions with amino acids flavor of boiled potato is forming (Janski, 2010). Methional, a product of Strecker degradation reaction, aliphatic alcohols and aldehydes (formed through lipid degradation), thiols and sulfides, and methoxypyrazines (originate from raw potato with intense contribution) are compounds responsible for the boiled aroma (Jansky, 2010). According to Thybo et al. (2006), group of volatiles are responsible for raw potato off-odor, which probably evaporate during boiling. Sour taste is developed during incomplete oxidation of sugars and deamination of amino acids, ascorbic acid, and polyphenolic acids and further some phenolic compounds could be responsible for bitter taste (Jansky, 2010; Vainionpää et al., 2000). Also, it should be pointed out that tubers' aging did not significantly affect the characteristic odor, off-odor, firmness, and sweet taste of boiled FCP.

ABA had a significant effect ($P \leq 0.05$) on characteristic odor, off-odor, firmness, characteristic taste, sweet, sour, bitter, and off-taste. Samples treated with SA had a less pronounced characteristic odor and more pronounced off-odor and firmness at the same time. Furthermore, characteristic taste and sweet taste were less pronounced, whereas sourness, bitterness, and off-taste were more pronounced in SA-treated samples. Regardless that statistical analysis showed significant differences in boiled potato among SC and SA, those differences were numerically very slight and combination of tubers' age × ABA showed significant influence only on color, sour taste, and off-taste.

Package atmosphere significantly affected ($P \leq 0.05$) color, firmness, creaminess, salty taste, sour taste, and off-taste. VP samples were scored as less brown than MAP samples. Also, VP samples were scored with greater firmness and less sour, salty, and off-taste, which indicates that VP is more acceptable for preservation of the FCP sensory properties as previously discussed.

The storage time of samples had a significant influence ($P \leq 0.05$) on all examined sensory properties. During storage, the color of samples was evaluated as browner, the characteristic odor was less pronounced, whereas off-odor and moistness were more noticeable. Furthermore, firmness, creaminess, characteristic taste, and sweet taste were less recognizable and intensity of sour, salty, bitter, and off-taste increased.

Table 4–Influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on sensory properties of boiled fresh-cut potato.

Source of variation	Color (Browning)	Characteristic odor	Off-odor	Moistness	Firmness	Creaminess	Characteristic taste	Sweet taste	Salty taste	Sour taste	Bitter taste	Off-taste
Cultivar	$P \leq 0.01^{A}$	$P = 0.64$	$P = 0.33$	$P \leq 0.01^{A}$	$P = 0.74$	$P = 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.77$	$P = 0.13$	$P = 0.15$	$P = 0.11$	$P \leq 0.01^{A}$
B	1.4 ± 0.0^{a1}	3.6 ± 0.1^{a1}	1.4 ± 0.0^{a1}	2.9 ± 0.1^{b}	2.5 ± 0.1^{a1}	3.5 ± 0.1^{b}	3.7 ± 0.1^{b}	1.7 ± 0.0^{a1}	1.3 ± 0.0^{a1}	1.5 ± 0.0^{a1}	1.2 ± 0.0^{a1}	1.4 ± 0.0^{a1}
LC	2.6 ± 0.0^{bA}	3.6 ± 0.1^{aA}	1.3 ± 0.0^{aA}	2.6 ± 0.1^{aA}	2.5 ± 0.1^{aA}	3.2 ± 0.1^{aA}	3.4 ± 0.1^{aA}	1.7 ± 0.0^{aA}	1.4 ± 0.0^{aA}	1.5 ± 0.0^{aA}	1.3 ± 0.0^{aA}	1.5 ± 0.0^{bA}
Tubers' age (month)	$P \leq 0.01^{A}$	$P = 0.09$	$P = 0.06$	$P = 0.04^{A}$	$P = 0.39$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.13$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$
1	1.8 ± 0.1^{aA}	3.6 ± 0.1^{aA}	1.4 ± 0.0^{aA}	2.6 ± 0.1^{aA}	2.4 ± 0.1^{aA}	3.6 ± 0.1^{bA}	3.7 ± 0.1^{bA}	1.8 ± 0.1^{aA}	1.3 ± 0.0^{aA}	1.4 ± 0.0^{aA}	1.1 ± 0.0^{aA}	1.3 ± 0.0^{bA}
5	1.9 ± 0.1^{a1}	3.5 ± 0.1^{a1}	1.3 ± 0.0^{a1}	2.7 ± 0.1^{a1}	2.5 ± 0.1^{a1}	3.1 ± 0.1^{a1}	3.6 ± 0.1^{b1}	1.6 ± 0.1^{a1}	1.2 ± 0.0^{a1}	1.3 ± 0.0^{a1}	1.2 ± 0.0^{a1}	1.1 ± 0.0^{a1}
9	2.2 ± 0.1^{bA}	3.7 ± 0.1^{aA}	1.4 ± 0.0^{aA}	2.9 ± 0.1^{aA}	2.5 ± 0.1^{aA}	3.4 ± 0.1^{bA}	3.3 ± 0.1^{aA}	1.6 ± 0.1^{aA}	1.7 ± 0.0^{bA}	1.8 ± 0.0^{bA}	1.5 ± 0.0^{bA}	2.0 ± 0.0^{cA}
ABA	$P = 0.80$	$P = 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.37$	$P = 0.01^{A}$	$P = 0.55$	$P = 0.04^{A}$	$P \leq 0.01^{A}$	$P = 1.00$	$P \leq 0.01^{A}$	$P = 0.02^{A}$	$P \leq 0.01^{A}$
SC	2.0 ± 0.0^{a}	3.7 ± 0.1^{b}	1.3 ± 0.0^{a}	2.8 ± 0.1^{a1}	2.4 ± 0.1^{a}	3.4 ± 0.1^{a1}	3.6 ± 0.1^{b}	1.8 ± 0.0^{b}	1.4 ± 0.0^{a}	1.4 ± 0.0^{a}	1.2 ± 0.0^{a}	1.3 ± 0.0^{a}
SA	2.0 ± 0.0^{a1}	3.5 ± 0.1^{a1}	1.4 ± 0.0^{b}	2.7 ± 0.1^{a1}	2.6 ± 0.1^{b}	3.3 ± 0.1^{a1}	3.4 ± 0.1^{a1}	1.5 ± 0.0^{a1}	1.4 ± 0.0^{a1}	1.6 ± 0.0^{b}	1.3 ± 0.0^{b}	1.6 ± 0.0^{b}
Package atmosphere	$P \leq 0.01^{A}$	$P = 0.30$	$P = 0.06$	$P = 0.13$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.36$	$P = 0.19$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.78$	$P = 0.01^{A}$
VP	1.8 ± 0.0^{a1}	3.7 ± 0.1^{a1}	1.3 ± 0.0^{a1}	2.7 ± 0.1^{a}	2.7 ± 0.1^{b}	3.2 ± 0.1^{a}	3.6 ± 0.1^{a}	1.7 ± 0.0^{a}	1.3 ± 0.0^{a}	1.4 ± 0.0^{a}	1.3 ± 0.0^{a}	1.4 ± 0.0^{a}
MAP	2.2 ± 0.0^{bA}	3.6 ± 0.1^{aA}	1.4 ± 0.0^{aA}	2.8 ± 0.1^{aA}	2.2 ± 0.1^{aA}	3.6 ± 0.1^{bA}	3.5 ± 0.1^{aA}	1.6 ± 0.0^{aA}	1.5 ± 0.0^{bA}	1.6 ± 0.0^{bA}	1.3 ± 0.0^{aA}	1.5 ± 0.0^{bA}
Storage time (day)	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$
0	2.0 ± 0.1^{abA}	3.9 ± 0.1^{cA}	1.4 ± 0.0^{bA}	2.5 ± 0.1^{aA}	2.7 ± 0.1^{cA}	3.9 ± 0.1^{cA}	3.9 ± 0.1^{cA}	1.7 ± 0.1^{aA}	1.1 ± 0.0^{aA}	1.1 ± 0.0^{aA}	1.2 ± 0.0^{aA}	1.1 ± 0.0^{aA}
2	2.0 ± 0.1^{abA}	3.4 ± 0.1^{bA}	1.2 ± 0.0^{aA}	2.7 ± 0.1^{abA}	2.8 ± 0.1^{cA}	2.8 ± 0.1^{aA}	3.5 ± 0.1^{bA}	1.9 ± 0.1^{bA}	1.5 ± 0.0^{bA}	1.5 ± 0.0^{bA}	1.4 ± 0.0^{bA}	1.3 ± 0.0^{bA}
4	1.8 ± 0.1^{aA}	4.2 ± 0.1^{dA}	1.1 ± 0.0^{aA}	2.8 ± 0.1^{bA}	2.4 ± 0.1^{bA}	3.4 ± 0.1^{bA}	4.0 ± 0.1^{cA}	1.6 ± 0.1^{aA}	1.2 ± 0.0^{aA}	1.3 ± 0.0^{aA}	1.2 ± 0.0^{aA}	1.2 ± 0.0^{abA}
8	2.2 ± 0.1^{bA}	3.0 ± 0.1^{aA}	1.6 ± 0.0^{cA}	2.9 ± 0.1^{bA}	2.0 ± 0.1^{aA}	3.3 ± 0.1^{bA}	2.7 ± 0.1^{aA}	1.5 ± 0.1^{aA}	1.7 ± 0.0^{cA}	2.1 ± 0.0^{cA}	1.4 ± 0.0^{bA}	2.2 ± 0.0^{cA}
Cultivar × tubers' age (month)	$P \leq 0.01^{A}$	$P = 0.38$	$P = 0.29$	$P = 0.68$	$P = 0.10$	$P = 0.70$	$P = 0.50$	$P = 0.21$	$P = 0.42$	$P = 0.01^{A}$	$P = 0.58$	$P = 0.01^{A}$
B × 1	1.3 ± 0.1^{a1}	3.5 ± 0.1^{a1}	1.4 ± 0.1^{a1}	2.8 ± 0.1^{a1}	2.5 ± 0.1^{a1}	3.8 ± 0.1^{a1}	3.8 ± 0.1^{a1}	1.7 ± 0.1^{a1}	1.2 ± 0.0^{a1}	1.4 ± 0.1^{a1}	1.1 ± 0.1^{a1}	1.3 ± 0.0^{b1}
B × 5	1.5 ± 0.1^{a1}	3.4 ± 0.1^{a1}	1.3 ± 0.1^{a1}	2.9 ± 0.1^{a1}	2.4 ± 0.1^{a1}	3.2 ± 0.1^{a1}	3.6 ± 0.1^{a1}	1.6 ± 0.1^{a1}	1.2 ± 0.0^{a1}	1.3 ± 0.1^{a1}	1.2 ± 0.1^{a1}	1.1 ± 0.0^{a1}
B × 9	1.5 ± 0.1^{a1}	3.8 ± 0.1^{a1}	1.4 ± 0.1^{a1}	3.0 ± 0.1^{a1}	2.5 ± 0.1^{a1}	3.5 ± 0.1^{a1}	3.5 ± 0.1^{a1}	1.7 ± 0.1^{a1}	1.6 ± 0.0^{a1}	1.7 ± 0.1^{b1}	1.4 ± 0.1^{a1}	1.8 ± 0.0^{c1}
LC × 1	2.3 ± 0.1^{b1}	3.6 ± 0.1^{a1}	1.3 ± 0.1^{a1}	2.5 ± 0.1^{a1}	2.3 ± 0.1^{a1}	3.5 ± 0.1^{a1}	3.6 ± 0.1^{a1}	1.8 ± 0.1^{a1}	1.3 ± 0.0^{a1}	1.4 ± 0.1^{a1}	1.1 ± 0.1^{a1}	1.3 ± 0.0^{b1}
LC × 5	2.4 ± 0.1^{b1}	3.6 ± 0.1^{a1}	1.2 ± 0.1^{a1}	2.5 ± 0.1^{a1}	2.6 ± 0.1^{a1}	2.9 ± 0.1^{a1}	3.5 ± 0.1^{a1}	1.6 ± 0.1^{a1}	1.2 ± 0.0^{a1}	1.3 ± 0.1^{a1}	1.3 ± 0.1^{a1}	1.1 ± 0.0^{ab1}
LC × 9	3.0 ± 0.1^{c1}	3.7 ± 0.1^{a1}	1.4 ± 0.1^{a1}	2.7 ± 0.1^{a1}	2.5 ± 0.1^{a1}	3.3 ± 0.1^{a1}	3.1 ± 0.1^{a1}	1.6 ± 0.1^{a1}	1.7 ± 0.0^{a1}	2.0 ± 0.1^{c1}	1.6 ± 0.1^{a1}	2.1 ± 0.0^{d1}
Tubers' age (month) × ABA	$P = 0.94$	$P = 0.50$	$P = 0.96$	$P = 0.13$	$P = 0.78$	$P = 0.69$	$P = 0.87$	$P = 0.46$	$P \leq 0.01^{A}$	$P = 0.17$	$P = 0.94$	$P = 0.10$
1 × SC	1.8 ± 0.1^{aA}	3.7 ± 0.1^{aA}	1.3 ± 0.1^{aA}	2.8 ± 0.1^{aA}	2.3 ± 0.1^{aA}	3.6 ± 0.1^{aA}	3.8 ± 0.1^{aA}	1.9 ± 0.1^{aA}	1.4 ± 0.0^{bcA}	1.3 ± 0.1^{aA}	1.1 ± 0.1^{aA}	1.2 ± 0.0^{aA}
1 × SA	1.8 ± 0.1^{aA}	3.4 ± 0.1^{aA}	1.4 ± 0.1^{aA}	2.5 ± 0.1^{aA}	2.5 ± 0.1^{aA}	3.6 ± 0.1^{aA}	3.6 ± 0.1^{aA}	1.6 ± 0.1^{aA}	1.2 ± 0.0^{aA}	1.5 ± 0.1^{aA}	1.2 ± 0.1^{aA}	1.4 ± 0.0^{aA}
5 × SC	2.0 ± 0.1^{aA}	3.7 ± 0.1^{aA}	1.2 ± 0.1^{aA}	2.6 ± 0.1^{aA}	2.5 ± 0.1^{aA}	3.2 ± 0.1^{aA}	3.7 ± 0.1^{aA}	1.7 ± 0.1^{aA}	1.1 ± 0.0^{aA}	1.3 ± 0.1^{aA}	1.2 ± 0.1^{aA}	1.0 ± 0.0^{aA}
5 × SA	1.9 ± 0.1^{aA}	3.3 ± 0.1^{aA}	1.3 ± 0.1^{aA}	2.7 ± 0.1^{aA}	2.6 ± 0.1^{aA}	3.0 ± 0.1^{aA}	3.4 ± 0.1^{aA}	1.5 ± 0.1^{aA}	1.2 ± 0.0^{abA}	1.3 ± 0.1^{aA}	1.3 ± 0.1^{aA}	1.2 ± 0.0^{aA}
9 × SC	2.2 ± 0.1^{aA}	3.8 ± 0.1^{aA}	1.3 ± 0.1^{aA}	2.9 ± 0.1^{aA}	2.4 ± 0.1^{aA}	3.4 ± 0.1^{aA}	3.4 ± 0.1^{aA}	1.8 ± 0.1^{aA}	1.6 ± 0.0^{cdA}	1.7 ± 0.1^{aA}	1.4 ± 0.1^{aA}	1.8 ± 0.0^{cA}
9 × SA	2.2 ± 0.1^{a1}	3.7 ± 0.1^{a1}	1.5 ± 0.1^{a1}	2.9 ± 0.1^{a1}	2.6 ± 0.1^{a1}	3.4 ± 0.1^{a1}	3.2 ± 0.1^{a1}	1.5 ± 0.1^{a1}	1.7 ± 0.0^{d1}	1.9 ± 0.1^{a1}	1.6 ± 0.1^{a1}	2.1 ± 0.0^{d1}
Grand mean	2.0	3.6	1.3	2.7	2.5	3.4	3.5	1.7	1.4	1.5	1.3	1.4

Note. Results are expressed as mean ± SE.
Abbreviations: B, Bingt.; LC, Lady Cline; ABA, antibrowning agent; SC, sodium chloride (1%); SA, sodium ascorbate (2%); VP, vacuum packaging; MAP, modified atmosphere packaging.
[A]Statistically significant variable at $P \leq 0.05$. Values with different letters are statistically different at $P \leq 0.05$.

Table 5–Influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on sensory properties of fried fresh-cut potato.

Source of variation	Color (Browning)	Characteristic odor	Off-odor	Oiliness	Firmness	Crispiness	Characteristic taste	Sweet taste	Salty taste	Sour taste	Bitter taste	Off-taste
Cultivar	$P \leq 0.01^{*}$	$P = 0.03^{*}$	$P = 0.41$	$P = 0.02^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P = 0.74$	$P = 0.10$	$P = 0.02^{*}$	$P = 0.95$	$P = 0.42$	$P = 0.11$
B	2.3 ± 0.1^{a}	3.8 ± 0.1^{b}	1.4 ± 0.0^{a}	2.7 ± 0.0^{b}	2.3 ± 0.1^{a}	1.8 ± 0.1^{a}	3.8 ± 0.1^{a}	2.4 ± 0.1^{a}	1.6 ± 0.1^{a}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	1.2 ± 0.0^{a}
LC	2.6 ± 0.1^{b}	3.6 ± 0.1^{a}	1.3 ± 0.0^{a}	2.5 ± 0.0^{a}	2.6 ± 0.1^{b}	2.1 ± 0.1^{b}	3.8 ± 0.1^{a}	2.3 ± 0.1^{a}	1.8 ± 0.1^{b}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	1.2 ± 0.0^{a}
Tubers' age (month)	$P = 0.50$	$P = 0.14$	$P = 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.03^{*}$	$P \leq 0.01^{*}$	$P = 0.99$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P = 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$
1	2.4 ± 0.1^{a}	3.7 ± 0.1^{a}	1.4 ± 0.0^{b}	2.4 ± 0.1^{a}	2.6 ± 0.1^{b}	2.2 ± 0.1^{b}	3.8 ± 0.1^{a}	2.6 ± 0.1^{b}	1.9 ± 0.1^{b}	1.3 ± 0.1^{ab}	1.1 ± 0.0^{a}	1.1 ± 0.0^{a}
5	2.5 ± 0.1^{a}	3.6 ± 0.1^{a}	1.3 ± 0.0^{a}	2.6 ± 0.1^{a}	2.5 ± 0.1^{ab}	2.0 ± 0.1^{a}	3.8 ± 0.1^{a}	2.2 ± 0.1^{a}	1.6 ± 0.1^{a}	1.2 ± 0.1^{a}	1.1 ± 0.0^{a}	1.1 ± 0.0^{a}
9	2.4 ± 0.1^{a}	3.8 ± 0.1^{a}	1.3 ± 0.0^{ab}	2.8 ± 0.1^{b}	2.4 ± 0.1^{a}	1.8 ± 0.1^{a}	3.8 ± 0.1^{a}	2.2 ± 0.1^{a}	1.6 ± 0.1^{a}	1.4 ± 0.1^{b}	1.3 ± 0.0^{b}	1.3 ± 0.0^{b}
ABA	$P \leq 0.01^{*}$	$P = 0.85$	$P = 0.04^{*}$	$P \leq 0.01^{*}$	$P = 0.08$	$P = 0.26$	$P \leq 0.01^{*}$	$P = 0.09$	$P = 0.21$	$P = 0.33$	$P = 0.36$	$P = 0.01^{*}$
SC	2.3 ± 0.1^{a}	3.7 ± 0.1^{a}	1.3 ± 0.0^{a}	2.4 ± 0.0^{a}	2.4 ± 0.1^{a}	1.9 ± 0.1^{a}	3.9 ± 0.1^{b}	2.4 ± 0.1^{a}	1.8 ± 0.1^{a}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	1.1 ± 0.0^{a}
SA	2.6 ± 0.1^{b}	3.7 ± 0.1^{a}	1.4 ± 0.0^{b}	2.8 ± 0.0^{b}	2.5 ± 0.1^{a}	2.0 ± 0.1^{a}	3.7 ± 0.1^{a}	2.3 ± 0.1^{a}	1.7 ± 0.1^{a}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	1.3 ± 0.0^{b}
Package atmosphere	$P \leq 0.01^{*}$	$P = 0.05$	$P = 0.01^{*}$	$P = 0.18$	$P = 0.12$	$P = 0.05^{*}$	$P = 0.74$	$P = 0.07$	$P \leq 0.01^{*}$	$P = 0.90$	$P = 0.96$	$P = 0.43$
VP	2.2 ± 0.1^{a}	3.8 ± 0.1^{a}	1.3 ± 0.0^{a}	2.6 ± 0.0^{a}	2.5 ± 0.1^{a}	2.1 ± 0.1^{a}	3.8 ± 0.1^{a}	2.3 ± 0.1^{a}	1.6 ± 0.1^{a}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	1.2 ± 0.0^{a}
MAP	2.7 ± 0.1^{b}	3.6 ± 0.1^{a}	1.4 ± 0.0^{b}	2.5 ± 0.0^{a}	2.4 ± 0.1^{a}	1.9 ± 0.1^{a}	3.8 ± 0.1^{a}	2.4 ± 0.1^{a}	1.8 ± 0.1^{b}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	1.2 ± 0.0^{a}
Storage time (day)	$P = 0.05^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$	$P = 0.02^{*}$	$P \leq 0.01^{*}$	$P = 0.01^{*}$	$P \leq 0.01^{*}$	$P = 0.05$	$P \leq 0.01^{*}$	$P \leq 0.01^{*}$
0	2.4 ± 0.1^{a}	4.1 ± 0.1^{c}	1.1 ± 0.0^{a}	2.4 ± 0.1^{a}	2.7 ± 0.1^{c}	2.0 ± 0.1^{ab}	4.0 ± 0.1^{b}	2.4 ± 0.1^{ab}	1.5 ± 0.1^{a}	1.3 ± 0.1^{a}	1.1 ± 0.0^{a}	1.2 ± 0.0^{ab}
2	2.3 ± 0.1^{a}	3.6 ± 0.1^{b}	1.3 ± 0.0^{b}	2.8 ± 0.1^{b}	2.3 ± 0.1^{ab}	1.8 ± 0.1^{a}	3.8 ± 0.1^{b}	2.4 ± 0.1^{b}	1.6 ± 0.1^{ab}	1.4 ± 0.1^{a}	1.3 ± 0.0^{b}	1.2 ± 0.0^{ab}
4	2.5 ± 0.1^{a}	4.0 ± 0.1^{c}	1.3 ± 0.0^{b}	2.8 ± 0.1^{b}	2.3 ± 0.1^{a}	2.1 ± 0.1^{b}	4.1 ± 0.1^{b}	2.5 ± 0.1^{b}	1.9 ± 0.1^{c}	1.2 ± 0.1^{a}	1.1 ± 0.0^{a}	1.1 ± 0.0^{a}
8	2.6 ± 0.1^{a}	3.1 ± 0.1^{a}	1.6 ± 0.0^{c}	2.4 ± 0.1^{a}	2.6 ± 0.1^{bc}	2.0 ± 0.1^{ab}	3.3 ± 0.1^{a}	2.1 ± 0.1^{a}	1.9 ± 0.1^{bc}	1.4 ± 0.1^{a}	1.3 ± 0.0^{b}	1.3 ± 0.0^{b}
Cultivar × tubers' age (month)	$P \leq 0.01^{*}$	$P = 0.29$	$P = 0.64$	$P = 0.37$	$P = 0.89$	$P = 0.22$	$P = 0.61$	$P = 0.57$	$P = 0.93$	$P = 0.64$	$P = 0.59$	$P = 0.84$
B × 1	2.4 ± 0.1^{ab}	3.8 ± 0.1^{a}	1.5 ± 0.1^{a}	2.5 ± 0.1^{a}	2.4 ± 0.1^{a}	2.1 ± 0.1^{a}	3.8 ± 0.1^{a}	2.7 ± 0.1^{a}	1.8 ± 0.1^{a}	1.2 ± 0.1^{a}	1.1 ± 0.0^{a}	$1.2 \pm 0.0a$
B × 5	2.2 ± 0.1^{a}	3.8 ± 0.1^{a}	1.3 ± 0.1^{a}	2.6 ± 0.1^{a}	2.3 ± 0.1^{a}	1.9 ± 0.1^{a}	3.8 ± 0.1^{a}	2.2 ± 0.1^{a}	1.6 ± 0.1^{a}	1.2 ± 0.1^{a}	1.2 ± 0.0^{a}	1.2 ± 0.0^{a}
B × 9	2.2 ± 0.1^{a}	3.8 ± 0.1^{a}	1.3 ± 0.1^{a}	2.9 ± 0.1^{a}	2.2 ± 0.1^{a}	1.5 ± 0.1^{a}	3.7 ± 0.1^{a}	2.3 ± 0.1^{a}	1.5 ± 0.1^{a}	1.5 ± 0.1^{a}	1.3 ± 0.0^{a}	1.4 ± 0.0^{a}
LC × 1	2.3 ± 0.1^{a}	3.5 ± 0.1^{a}	1.4 ± 0.1^{a}	2.3 ± 0.1^{a}	2.8 ± 0.1^{a}	2.3 ± 0.1^{a}	3.8 ± 0.1^{a}	2.4 ± 0.1^{a}	2.0 ± 0.1^{a}	1.3 ± 0.1^{a}	1.1 ± 0.0^{a}	1.1 ± 0.0^{a}
LC × 5	2.8 ± 0.1^{b}	3.5 ± 0.1^{a}	1.2 ± 0.1^{a}	2.5 ± 0.1^{a}	2.6 ± 0.1^{a}	2.0 ± 0.1^{a}	3.8 ± 0.1^{a}	2.1 ± 0.1^{a}	1.7 ± 0.1^{a}	1.2 ± 0.1^{a}	1.1 ± 0.0^{a}	1.1 ± 0.0^{a}
LC × 9	2.7 ± 0.1^{b}	3.8 ± 0.1^{a}	1.3 ± 0.1^{a}	2.8 ± 0.1^{a}	2.5 ± 0.1^{a}	2.0 ± 0.1^{a}	3.9 ± 0.1^{a}	2.2 ± 0.1^{a}	1.7 ± 0.1^{a}	1.4 ± 0.1^{a}	1.3 ± 0.0^{a}	1.3 ± 0.0^{a}
Tubers' age (month) × ABA	$P = 0.17$	$P = 0.97$	$P \leq 0.01^{*}$	$P = 0.94$	$P = 0.75$	$P = 0.81$	$P = 0.50$	$P = 0.16$	$P = 0.84$	$P = 0.52$	$P = 0.53$	$P = 0.16$
1 × SC	2.2 ± 0.1^{a}	3.6 ± 0.1^{a}	1.3 ± 0.1^{a}	2.2 ± 0.1^{a}	2.6 ± 0.1^{a}	2.1 ± 0.1^{a}	3.9 ± 0.1^{a}	2.5 ± 0.1^{a}	2.0 ± 0.1^{a}	1.2 ± 0.1^{a}	1.1 ± 0.0^{a}	1.1 ± 0.0^{a}
1 × SA	2.6 ± 0.1^{a}	3.7 ± 0.1^{a}	1.6 ± 0.1^{b}	2.6 ± 0.1^{a}	2.6 ± 0.1^{a}	2.3 ± 0.1^{a}	3.7 ± 0.1^{a}	2.6 ± 0.1^{a}	1.9 ± 0.1^{a}	1.3 ± 0.1^{a}	1.1 ± 0.0^{a}	1.2 ± 0.0^{a}
5 × SC	2.3 ± 0.1^{a}	3.7 ± 0.1^{a}	1.2 ± 0.1^{a}	2.4 ± 0.1^{a}	2.4 ± 0.1^{a}	1.9 ± 0.1^{a}	4.0 ± 0.1^{a}	2.3 ± 0.1^{a}	1.7 ± 0.1^{a}	1.2 ± 0.1^{a}	1.1 ± 0.0^{a}	1.0 ± 0.0^{a}
5 × SA	2.7 ± 0.1^{a}	3.6 ± 0.1^{a}	1.3 ± 0.1^{a}	2.7 ± 0.1^{a}	2.5 ± 0.1^{a}	2.0 ± 0.1^{a}	3.6 ± 0.1^{a}	2.0 ± 0.1^{a}	1.6 ± 0.1^{a}	1.3 ± 0.1^{a}	1.2 ± 0.0^{a}	1.2 ± 0.0^{a}
9 × SC	2.4 ± 0.1^{a}	3.8 ± 0.1^{a}	1.3 ± 0.1^{a}	2.7 ± 0.1^{a}	2.3 ± 0.1^{a}	1.7 ± 0.1^{a}	3.9 ± 0.1^{a}	2.4 ± 0.1^{a}	1.7 ± 0.1^{a}	1.5 ± 0.1^{a}	1.3 ± 0.0^{a}	1.3 ± 0.0^{a}
9 × SA	2.5 ± 0.1^{a}	3.9 ± 0.1^{a}	1.3 ± 0.1^{a}	3.0 ± 0.1^{a}	2.5 ± 0.1^{a}	1.8 ± 0.1^{a}	3.7 ± 0.1^{a}	2.1 ± 0.1^{a}	1.5 ± 0.1^{a}	1.4 ± 0.1^{a}	1.3 ± 0.0^{a}	1.4 ± 0.0^{a}
Grand mean	2.4	3.7	1.3	2.6	2.5	2.0	3.8	2.3	1.7	1.3	1.2	1.2

Note. Results are expressed as mean ± SE.
Abbreviations: B, Birgit; LC, Lady Claire; ABA, antibrowning agent; SC, sodium chloride (1%); SA, sodium ascorbate (2%); VP, vacuum packaging; MAP, modified atmosphere packaging.
[a] Statistically significant variable at $P \leq 0.05$. Values with different letters are statistically different at $P \leq 0.05$.

Table 6–Influence of cultivar, tubers' age, antibrowning agent, package atmosphere, and storage time on sensory properties of baked fresh-cut potato.

Source of variation	Color (Browning)	Characteristic odor	Off-odor	Oiliness	Firmness	Crispiness	Characteristic taste	Sweet taste	Salty taste	Sour taste	Bitter taste	Off-taste
Cultivar	$P \leq 0.01^{A}$	$P = 0.15$	$P = 0.51$	$P = 0.26$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.72$	$P = 0.94$	$P = 0.01^{A}$	$P = 0.22$	$P = 0.02^{A}$	$P = 0.78$
B	2.6 ± 0.1^{a}	3.6 ± 0.1^{a}	1.6 ± 0.1^{a}	3.0 ± 0.1^{a}	2.6 ± 0.0^{a}	2.2 ± 0.1^{a}	3.6 ± 0.1^{a}	1.9 ± 0.1^{a}	1.4 ± 0.0^{a}	1.5 ± 0.0^{a}	1.3 ± 0.0^{a}	1.4 ± 0.1^{a}
LC	3.3 ± 0.1^{b}	3.5 ± 0.1^{a}	1.6 ± 0.1^{a}	2.9 ± 0.1^{a}	3.0 ± 0.0^{b}	2.5 ± 0.1^{b}	3.5 ± 0.1^{a}	1.9 ± 0.1^{a}	1.5 ± 0.0^{b}	1.5 ± 0.0^{a}	1.5 ± 0.0^{b}	1.4 ± 0.1^{a}
Tubers' age (month)	$P = 0.01^{A}$	$P = 0.30$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.05$	$P \leq 0.01^{A}$	$P = 0.41$	$P = 0.01^{A}$	$P = 0.04^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$
1	3.0 ± 0.1^{ab}	3.4 ± 0.1^{a}	1.9 ± 0.1^{c}	2.9 ± 0.1^{a}	2.8 ± 0.1^{a}	2.9 ± 0.1^{b}	3.5 ± 0.1^{a}	2.0 ± 0.1^{b}	1.5 ± 0.0^{a}	1.4 ± 0.1^{a}	1.5 ± 0.1^{b}	1.3 ± 0.1^{a}
5	2.8 ± 0.1^{a}	3.6 ± 0.1^{a}	1.3 ± 0.1^{a}	2.8 ± 0.1^{a}	2.7 ± 0.1^{a}	2.0 ± 0.1^{a}	3.6 ± 0.1^{a}	1.8 ± 0.1^{ab}	1.3 ± 0.0^{a}	1.4 ± 0.1^{a}	1.3 ± 0.1^{a}	1.2 ± 0.1^{a}
9	3.1 ± 0.1^{b}	3.6 ± 0.1^{a}	1.6 ± 0.1^{b}	3.1 ± 0.1^{b}	2.9 ± 0.1^{a}	2.1 ± 0.1^{a}	3.6 ± 0.1^{a}	1.7 ± 0.1^{a}	1.5 ± 0.0^{a}	1.7 ± 0.1^{b}	1.5 ± 0.1^{b}	1.7 ± 0.1^{b}
ABA	$P \leq 0.01^{A}$	$P = 0.41$	$P = 0.02^{A}$	$P = 0.20$	$P = 0.77$	$P = 0.17$	$P = 0.07$	$P = 0.37$	$P = 0.34$	$P = 0.20$	$P = 0.03^{A}$	$P = 0.19$
SC	2.7 ± 0.1^{a}	3.6 ± 0.1^{a}	1.5 ± 0.1^{a}	2.9 ± 0.1^{a}	2.8 ± 0.0^{a}	2.4 ± 0.1^{a}	3.6 ± 0.1^{a}	1.9 ± 0.1^{a}	1.5 ± 0.0^{a}	1.5 ± 0.0^{a}	1.4 ± 0.0^{a}	1.4 ± 0.1^{a}
SA	3.3 ± 0.1^{b}	3.5 ± 0.1^{a}	1.7 ± 0.1^{b}	3.0 ± 0.1^{a}	2.8 ± 0.0^{a}	2.3 ± 0.1^{a}	3.5 ± 0.1^{a}	1.8 ± 0.1^{a}	1.4 ± 0.0^{a}	1.5 ± 0.0^{a}	1.5 ± 0.0^{b}	1.5 ± 0.1^{a}
Package atmosphere	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.91$	$P = 0.07$	$P = 0.03^{A}$	$P = 0.19$	$P = 0.94$	$P = 0.34$	$P = 0.68$	$P = 0.01^{A}$	$P = 0.26$
VP	2.7 ± 0.1^{b}	3.7 ± 0.1^{b}	1.5 ± 0.1^{a}	2.9 ± 0.1^{a}	2.9 ± 0.0^{a}	2.3 ± 0.1^{a}	3.6 ± 0.1^{a}	1.9 ± 0.1^{a}	1.4 ± 0.0^{a}	1.5 ± 0.0^{a}	1.3 ± 0.0^{a}	1.4 ± 0.1^{a}
MAP	3.2 ± 0.1^{a}	3.4 ± 0.1^{a}	1.8 ± 0.1^{b}	2.9 ± 0.1^{a}	2.7 ± 0.0^{a}	2.4 ± 0.1^{b}	3.5 ± 0.1^{a}	1.9 ± 0.1^{a}	1.5 ± 0.0^{a}	1.5 ± 0.0^{a}	1.5 ± 0.0^{b}	1.5 ± 0.1^{a}
Storage time (day)	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.86$	$P = 0.22$	$P = 0.39$	$P \leq 0.01^{A}$	$P = 0.02^{A}$	$P \leq 0.01^{A}$	$P \leq 0.01^{A}$	$P = 0.02^{A}$	$P = 0.01^{A}$
0	3.1 ± 0.1^{bc}	3.8 ± 0.1^{c}	1.6 ± 0.1^{a}	2.9 ± 0.1^{a}	2.7 ± 0.1^{a}	2.4 ± 0.1^{a}	3.7 ± 0.1^{b}	1.8 ± 0.1^{ab}	1.3 ± 0.0^{ab}	1.4 ± 0.1^{a}	1.3 ± 0.1^{a}	1.5 ± 0.1^{b}
2	2.8 ± 0.1^{a}	3.5 ± 0.1^{b}	1.4 ± 0.1^{a}	2.9 ± 0.1^{a}	2.7 ± 0.1^{a}	2.3 ± 0.1^{a}	3.5 ± 0.1^{b}	2.1 ± 0.1^{b}	1.5 ± 0.0^{bc}	1.5 ± 0.1^{ab}	1.5 ± 0.1^{ab}	1.5 ± 0.1^{ab}
4	2.8 ± 0.1^{ab}	3.8 ± 0.1^{bc}	1.6 ± 0.1^{a}	3.0 ± 0.1^{a}	2.9 ± 0.1^{a}	2.3 ± 0.1^{a}	3.8 ± 0.1^{b}	1.7 ± 0.1^{a}	1.3 ± 0.0^{a}	1.4 ± 0.1^{a}	1.4 ± 0.1^{ab}	1.2 ± 0.1^{a}
8	3.2 ± 0.1^{c}	3.0 ± 0.1^{a}	2.0 ± 0.1^{b}	3.0 ± 0.1^{a}	2.8 ± 0.1^{a}	2.4 ± 0.1^{a}	3.1 ± 0.1^{a}	1.8 ± 0.1^{ab}	1.6 ± 0.0^{c}	1.7 ± 0.1^{b}	1.5 ± 0.1^{b}	1.5 ± 0.1^{b}
Cultivar × tubers' age (month)	$P \leq 0.01^{A}$	$P = 0.93$	$P = 0.21$	$P = 0.66$	$P = 0.46$	$P = 0.41$	$P = 0.19$	$P = 0.61$	$P = 0.29$	$P = 0.44$	$P = 0.61$	$P = 0.13$
B × 1	3.0 ± 0.1^{b}	3.5 ± 0.1^{a}	1.9 ± 0.1^{a}	2.9 ± 0.1^{a}	2.6 ± 0.1^{a}	2.7 ± 0.1^{a}	3.4 ± 0.1^{a}	2.0 ± 0.1^{a}	1.4 ± 0.1^{a}	1.5 ± 0.1^{a}	1.4 ± 0.1^{a}	1.4 ± 0.1^{a}
B × 5	2.2 ± 0.1^{a}	3.6 ± 0.1^{a}	1.4 ± 0.1^{a}	2.9 ± 0.1^{a}	2.5 ± 0.1^{a}	2.0 ± 0.1^{a}	3.7 ± 0.1^{a}	1.9 ± 0.1^{a}	1.3 ± 0.1^{a}	1.4 ± 0.1^{a}	1.2 ± 0.1^{a}	1.3 ± 0.1^{a}
B × 9	2.8 ± 0.1^{b}	3.7 ± 0.1^{a}	1.6 ± 0.1^{a}	3.1 ± 0.1^{a}	2.6 ± 0.1^{a}	2.0 ± 0.1^{a}	3.6 ± 0.1^{a}	1.7 ± 0.1^{a}	1.4 ± 0.1^{a}	1.7 ± 0.1^{a}	1.5 ± 0.1^{a}	1.6 ± 0.1^{a}
LC × 1	3.0 ± 0.1^{bc}	3.4 ± 0.1^{a}	2.0 ± 0.1^{a}	2.8 ± 0.1^{a}	3.0 ± 0.1^{a}	3.0 ± 0.1^{a}	3.6 ± 0.1^{a}	2.0 ± 0.1^{a}	1.6 ± 0.1^{a}	1.3 ± 0.1^{a}	1.6 ± 0.1^{a}	1.3 ± 0.1^{a}
LC × 5	3.5 ± 0.1^{d}	3.5 ± 0.1^{a}	1.2 ± 0.1^{a}	2.8 ± 0.1^{a}	2.9 ± 0.1^{a}	2.1 ± 0.1^{a}	3.5 ± 0.1^{a}	1.8 ± 0.1^{a}	1.4 ± 0.1^{a}	1.4 ± 0.1^{a}	1.3 ± 0.1^{a}	1.2 ± 0.1^{a}
LC × 9	3.4 ± 0.1^{cd}	3.5 ± 0.1^{a}	1.6 ± 0.1^{a}	3.1 ± 0.1^{a}	3.1 ± 0.1^{a}	2.3 ± 0.1^{a}	3.5 ± 0.1^{a}	1.8 ± 0.1^{a}	1.5 ± 0.1^{a}	1.7 ± 0.1^{a}	1.6 ± 0.1^{a}	1.8 ± 0.1^{a}
Tubers' age (month) × ABA	$P = 0.60$	$P = 0.97$	$P = 0.87$	$P = 0.56$	$P = 0.34$	$P = 0.75$	$P = 0.83$	$P = 0.67$	$P = 0.24$	$P = 0.02^{A}$	$P = 0.01^{A}$	$P = 0.87$
1 × SC	2.7 ± 0.1^{a}	3.5 ± 0.1^{a}	1.8 ± 0.1^{a}	2.9 ± 0.1^{a}	2.7 ± 0.1^{a}	3.0 ± 0.1^{a}	3.5 ± 0.1^{a}	2.0 ± 0.1^{a}	1.5 ± 0.1^{a}	1.5 ± 0.1^{a}	1.6 ± 0.1^{b}	1.3 ± 0.1^{a}
1 × SA	3.3 ± 0.1^{a}	3.4 ± 0.1^{a}	2.0 ± 0.1^{a}	2.9 ± 0.1^{a}	2.9 ± 0.1^{a}	2.8 ± 0.1^{a}	3.4 ± 0.1^{a}	2.0 ± 0.1^{a}	1.5 ± 0.1^{a}	1.3 ± 0.1^{a}	1.4 ± 0.1^{ab}	1.4 ± 0.1^{a}
5 × SC	2.5 ± 0.1^{a}	3.6 ± 0.1^{a}	1.2 ± 0.1^{a}	2.8 ± 0.1^{a}	2.7 ± 0.1^{a}	2.1 ± 0.1^{a}	3.6 ± 0.1^{a}	1.9 ± 0.1^{a}	1.4 ± 0.1^{a}	1.4 ± 0.1^{a}	1.1 ± 0.1^{a}	1.2 ± 0.1^{a}
5 × SA	3.1 ± 0.1^{a}	3.5 ± 0.1^{a}	1.4 ± 0.1^{a}	2.9 ± 0.1^{a}	2.7 ± 0.1^{a}	1.9 ± 0.1^{a}	3.5 ± 0.1^{a}	1.7 ± 0.1^{a}	1.3 ± 0.1^{a}	1.4 ± 0.1^{a}	1.4 ± 0.1^{ab}	1.3 ± 0.1^{a}
9 × SC	2.8 ± 0.1^{a}	3.6 ± 0.1^{a}	1.5 ± 0.1^{a}	3.0 ± 0.1^{a}	2.9 ± 0.1^{a}	2.2 ± 0.1^{a}	3.7 ± 0.1^{a}	1.8 ± 0.1^{a}	1.5 ± 0.1^{a}	1.6 ± 0.1^{a}	1.4 ± 0.1^{ab}	1.6 ± 0.1^{a}
9 × SA	3.3 ± 0.1^{a}	3.6 ± 0.1^{a}	1.7 ± 0.1^{a}	3.2 ± 0.1^{a}	2.9 ± 0.1^{a}	2.1 ± 0.1^{a}	3.5 ± 0.1^{a}	1.7 ± 0.1^{a}	1.5 ± 0.1^{a}	1.9 ± 0.1^{b}	1.6 ± 0.1^{b}	1.8 ± 0.1^{a}
Grand mean	3.0	3.5	1.6	2.9	2.8	2.4	3.5	1.9	1.4	1.5	1.4	1.4

Note. Results are expressed as mean ± SE.
Abbreviations: B, Birgit; LC, Lady Claire; ABA, antibrowning agent; SC, sodium chloride (1%); SA, sodium ascorbate (2%); VP, vacuum packaging; MAP, modified atmosphere packaging.
[A]Statistically significant variable at $P \leq 0.05$. Values with different letters are statistically different at $P \leq 0.05$.

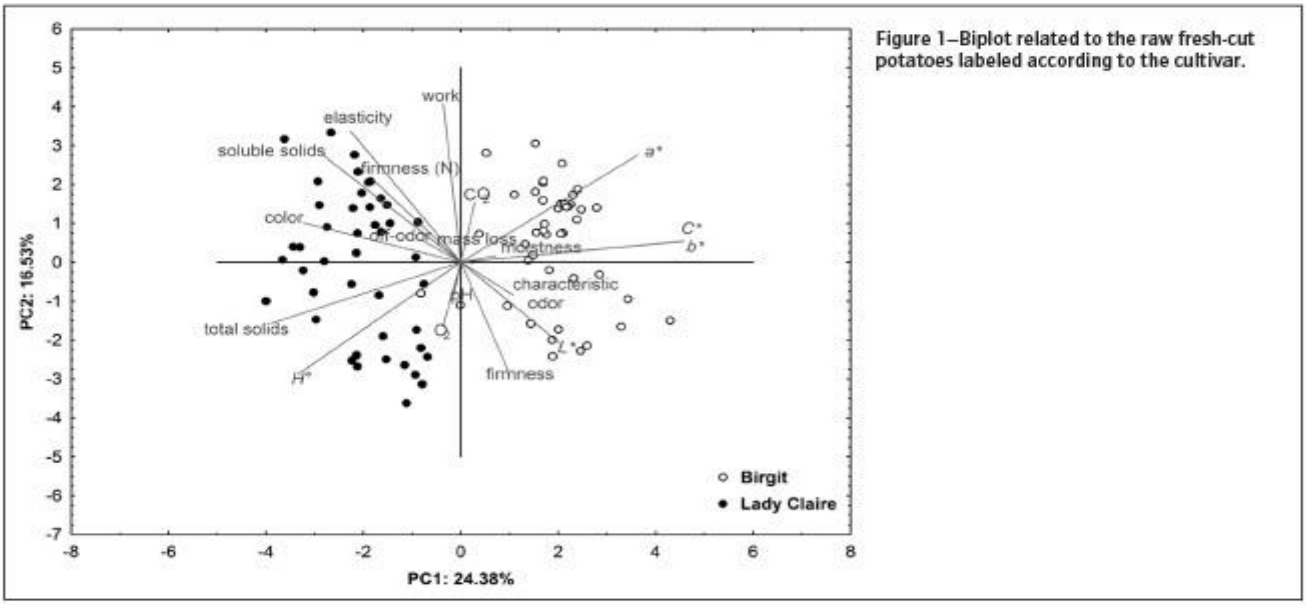

Figure 1–Biplot related to the raw fresh-cut potatoes labeled according to the cultivar.

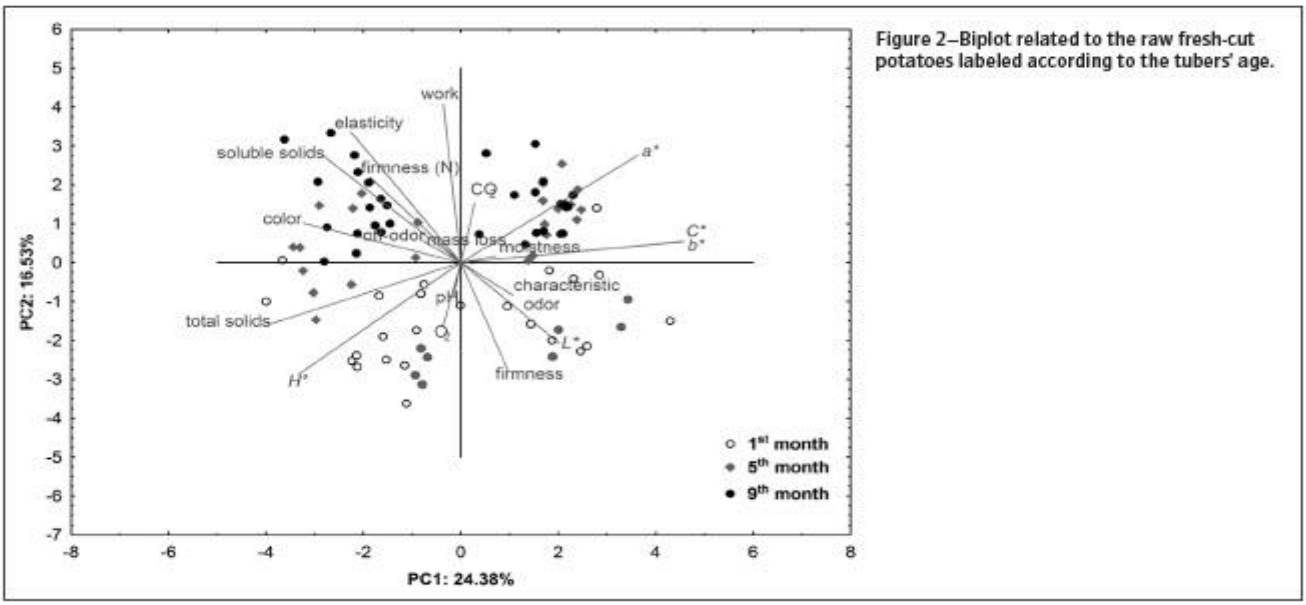

Figure 2–Biplot related to the raw fresh-cut potatoes labeled according to the tubers' age.

Although statistical analysis showed a significant effect of storage time on sensory attributes of boiled FCP, differences were numerically very slight for most attributes, especially till the fourth day. The most undesirable changes of attributes were noticed at the eighth day: loss of characteristic odor and taste as well as appearance of off-odor and off-taste.

According to the obtained results, it seems that more impact on sensory attributes of boiled FCP had storage time than tubers' aging.

3.5.3 Fried and baked samples. Considering popularity of fried and baked potato, another objective of this research was to ascertain appropriateness of obtained FCP for frying and baking regarding how all sources of variation in FCP processing affect sensory properties of fried and baked FCP. Sensory scores for fried and baked FCP are shown in Tables 5 and 6. In general, trends for all investigated attributes were similar in both applied thermal treatments. Additionally, grand means of all desirable attributes were higher for fried FCP compared to baked FCP and inversely, grand means of all undesirable attributes were lower for fried FCP compared to the baked ones.

Particular interest of this research was focused on influence of tubers' aging. Tubers' age significantly ($P \leq 0.05$) decreased off-odor, crispiness, sweet, and salty taste as well as it increased oiliness, sour, bitter, and off-taste of fried and baked samples. In fried

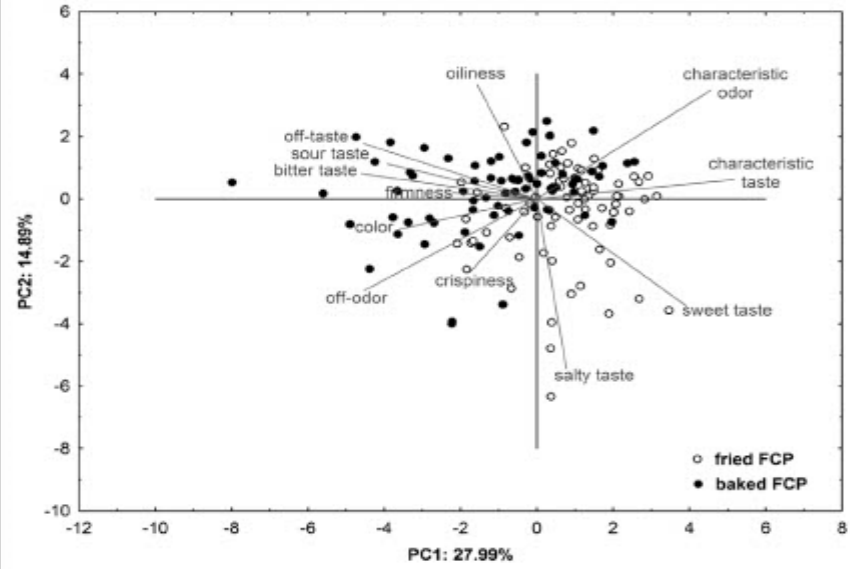

Figure 3–Biplot related to the fried and baked fresh-cut potatoes labeled according to the cooking method.

samples, tubers' age also affected firmness, where it decreased with tubers' aging. Additionally, tubers' age had impact on color in baked samples, which were scored as browner during aging.

Storage time significantly influenced ($P \leq 0.05$) on all examined sensory attributes of fried samples, except sour taste, whereas in baked samples significant influence was absent for texture attributes ($P > 0.05$). During storage, color was noticed as browner, characteristic odor was less pronounced, whereas off-odor was more present. Samples became less firmed and retained almost the same crispiness. Characteristic taste and sweetness were less pronounced, whereas intensity of sour, salty, bitter, and off-taste increased. Similar sensory results were obtained in baked samples.

Cultivar type significantly affected ($P \leq 0.05$) color, firmness, crispiness, and salty taste in fried and baked samples. Cv. Birgit samples were scored as less brown, less firmed, less crispy, and salty in comparison with cv. Lady Claire. Besides, in fried samples, cultivar type significantly influenced characteristic odor and oiliness. Cv. Birgit scored as a cultivar with more pronounced characteristic odor and oiliness. Among baked samples, cultivar differentiated in bitterness, where cv. Lady Claire scored as more bitter.

ABA showed a significant influence ($P \leq 0.05$) on color and off-odor of fried and baked samples, where these attributes were scored with lower scores in samples treated with SC. Moreover, ABA also affected oiliness, characteristic taste, and off-taste in fried samples. Samples treated with SC had less pronounced oiliness and off-taste with a more pronounced characteristic taste. In baked samples, ABA showed a significant influence on bitterness, where SC-treated samples were scored as less bitter.

Package atmosphere significantly influenced ($p \leq 0.05$) on color, off-odor and crispiness of fried and baked samples. Color and off-odor were evaluated as less pronounced in VP samples. Crispiness was higher scored in VP fried samples, while it was less pronounced in baked VP samples. In fried samples package atmosphere affected saltiness, where VP samples were less salty compared to MAP samples. Considering baked samples, package atmosphere affected characteristic taste and bitterness, where VP samples were scored as samples with a more pronounced characteristic taste and less bitterness.

Despite such statistical results, the numerical changes were negligible for most of evaluated attributes. Tubers' aging did not significantly affect characteristic taste either in fried or baked FCP in contrast to storage time of FCP especially after fourth day. The changes that occur in tubers during aging have no negative impact on taste particularly according to Jansky (2010) as well as overall FCP quality, although more attributes were slightly better evaluated till the first 5 months of tubers' storage and within the first 4 days of FCP storage. The aroma of a fried and baked potato is characterized by thermal lipid degradation products, Maillard reaction products (the result of reactions between amino acids or free amino groups of proteins and peptides and reducing sugars on a temperature higher than 100 °C), sulfur compounds, and methoxypyrazines. Pyrazines formed from Maillard reaction have a positive influence on sensory acceptance (Maga & Holm, 1992; Oruna-Concha, Duckham, & Ames, 2001).

3.6 PCA results

Possible grouping of raw FCP samples regarding cultivar type, tubers' age, ABA treatment, package atmosphere, and storage time was tested using PCA and obtained results are presented in Figures 1 and 2. Moreover, PCA was also conducted among fried and baked FCP in order to examine possible differences between sensory properties of FCP prepared by those two thermal treatments (Figure 3).

PCA showed grouping of raw FCP by cultivar type (Figure 1) and tubers' aging (Figure 2), whereas grouping according to the other applied conditions was not observed. The first two components explained 40.91% of the total variance. Considering the cultivar type, almost all cv. Birgit samples were situated at positive values of PC1, whereas samples of cv. Lady Claire were grouped at negative values of PC1 of the biplot. As for tubers' aging, the majority of samples from first month were placed at negative values of PC2, whereas ninth month samples were distributed at positive values of PC2 of the biplot. Analysis showed that TS, a^*, b^*, C^*,

H°, elasticity, work, and sensorially evaluated color were considered as the most discriminating variables due to strong/very strong correlation ($r = 0.65$ to 0.92) with both principal components, whereas SS, L^*, firmness, and sensorial firmness showed moderate correlation with PC1 and PC2 ($r = 0.40$ to 0.57), which is in accordance with previously discussed data (Tables 1, 2, and 3).

Regarding fried and baked FCP, the first two components explained 42.88% of the total variance and partial grouping of the sample can be observed. The distribution of fried FCP was placed mainly at positive values of PC1, whereas the majority of baked FCP samples took place at negative values of PC1 of the biplot. Characteristic odor, off-odor, characteristic taste, salty, bitter, and off-taste represented the most discriminating variables because they strongly correlated ($r = 0.65$ to 0.78) with PC1 and PC2, whereas sensory properties of color, oiliness, sweetness, and sourness moderately correlated with both principal components ($r = 0.42$ to 0.56).

4. CONCLUSIONS

This study showed that 9 months of aging of potato tubers had a significant impact on almost all investigated properties of FCP, but differences among first, fifth, and ninth months were numerically feeble for some parameters in raw samples: TS changed from 22.14% to 20.98%, SS 5.53% to 6.93%, pH 6.02 to 5.98, L^* 70.10 to 68.87, C^* 35.75 to 36.70, H° 89.29 to 88.15, and firmness 7.25 to 8.13N. Furthermore, it is of utmost importance to emphasize that 9 months of aging had no significant influence on the characteristic odor of raw, boiled, fried, and baked FCP and characteristic taste of fried and baked FCP, whereas characteristic taste of boiled ones remained unchanged for 5 months of aging. Considering frying and baking have some similarities in preparing procedure (high temperature and use of oil), some specific sensory properties are common (crispness and oiliness) and products are generally comparable. Regarding the comparison between fried and baked FCP, fried samples were better sensory evaluated than baked ones during all 9 months of tubers' storage. Additional investigation is necessary to examine the effect of tubers' age on the occurrence of acrylamide in fried FCP. Also, the results of this study showed that cv. Birgit is more suitable for FCP production than cv. Lady Claire during 9 months of tubers' aging, as well as that vacuum packaging and sodium ascorbate have more effectiveness on the preservation of FCP physical, chemical, and sensory properties.

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AUTHOR CONTRIBUTIONS

Draženka Dite Hunjek conducted the experiment, analyzed the data, and drafted the manuscript. Tanja Pranjić participated in one part of the analysis. Maja Repajić contributed to the statistical analysis and interpretation of the data as well as revised the manuscript. Branka Levaj conceived the original idea and designed the study, contributed to the discussion and data interpretation, and revised the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Chapter 4

Publication No. 3: Chemical Constituents of Fresh-cut potato as affected by Cultivar, Age, Storage and Cooking

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Chemical constituents of fresh-cut potato as affected by cultivar, age, storage, and cooking

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Abstract: Certain changes in phenolics and sugars can occur during the storage of potatoes, where particularly amounts of sugars represent the critical factor as they are involved in potentially harmful acrylamide (AA) formation during frying. This research investigates the impact of cultivars (Birgit and Lady Claire), tuber's age (1, 5, and 9 months), and storage duration (1, 5, and 8 days at 10 °C) on the content of phenolics and sugars in raw, boiled, and fried fresh-cut potato (FCP). The influence of these factors on the formation of AA in fried FCP was also assessed. Significant differences in phenolics and sugars were observed between cultivars (cv. Birgit contained 5.77 mg of phenolics 100 g^{-1} of dry weight (DW) and 1.75 g of sugars 100 g^{-1} DW, while cv. Lady Claire contained 10.13 mg of phenolics 100 g^{-1} DW and 0.65 g of sugars 100 g^{-1} DW). The content of phenolics significantly decreased, while sugars increased during tubers' aging. FCP storage time had no significant influence on the content of phenolics and sugars. The phenolics and sugars were the highest in the raw samples and the lowest in the boiled ones. Although the AA level in fried samples was significantly influenced by cultivar (Birgit > Lady Claire) and it increased with FCP storage time, it was below European Food Safety Authority (EFSA) regulation's approved maximum value (750 μg kg^{-1} FW) in both cultivars. Therefore, cvs. Birgit and Lady Claire could be considered as promising FCP cultivars and for frying purposes.

Practical Application: The results of this research reveal that quantitative changes of chemical constituents occurring during storage and cooking of fresh-cut slices of potato cultivars Birgit and Lady Claire are not a concern. This is of particular importance to fresh-cut producers and customers. Phenolics were reduced during storage, but they were still present in all cooked samples independently of the cooking method. The analysis of sugars showed that tubers as old as 9 months could be used for fresh-cut potato processing, providing safe frying without critical levels of acrylamide.

KEYWORDS
acrylamide, Birgit, Lady Claire, minimally processed potato, polyphenols, sugars

1 | INTRODUCTION

"Potato—the hidden treasure" was the motto of the International Year of the potato 2008, declared by The United Nations General Assembly (Lutaladio & Castaldi, 2009). This is not surprising since potato (*Solanum tuberosum* L.) is known for its nutritive value and is considered to be the fourth most important human food crop after rice, wheat, and maize (Zhu et al., 2010). It has been reported that potato provides more dry matter and protein per unit of growing area than cereals (Birch et al., 2012; Camire et al., 2009). Potato contains 80% of water, but also a high level of starch, which presents roughly 60 to 80% of dry matter (Dourado et al., 2019; Lutaladio & Castaldi, 2009). Starch is composed of amylose and amylopectin in the ratio of 1:3, where amylose, as slowly digestible, is health beneficial (Bodinham et al., 2010; Camire et al., 2009; Kaur & Singh, 2016; Monro & Mishra, 2009). Additionally, potato proteins are characterized by a high biological value similar to eggs (Camire et al., 2009; van Vliet et al., 2015). Moreover, potato is rich in iron, vitamins C, B1, B3, and B6, potassium, phosphorus, magnesium, folate, pantothenic acid, and riboflavin, as well as antioxidants (phenolics) (Lutaladio & Castaldi, 2009; Navarre et al., 2016).

Potato is usually present in the market as unprocessed, but it is also a favorable raw material for processing by freezing (e.g., French fries—chips, pommes frites), drying (e.g., flakes as instant mashed), or for snack production (e.g., crisps, chips) (Camire et al., 2009). Nevertheless, in the past decades, the fresh-cut potato (FCP) has been recognized by consumers as a very attractive concept. It is minimally processed and therefore healthier than highly processed foods, but also convenient, as it makes meal preparing process faster (Silveira et al., 2017; Tudela et al., 2002). Quality and shelf-life of FCP can be influenced by the type of potato cultivar, postharvest handling, storage conditions, tuber's age, fresh-cut processing (peeling, cutting, application of antibrowning agents), and packaging (Dite Hunjek et al., 2020a, 2020b; Silveira et al., 2017), as well as the distribution and selling conditions. Furthermore, all listed factors have an influence on the chemical composition of FCP in the raw state, which consequently affects the chemical composition of boiled or fried potatoes.

Phenolics are plants' secondary metabolites, protecting plants against bacteria, fungi, viruses, and insects (Akyol et al., 2016). They also exhibit positive effects on human health due to their antioxidant properties and are therefore recognized as protective against cancer, cardiovascular diseases, diabetes, etc. (Cory et al., 2018; Manach et al., 2004). In potatoes, phenolics are mostly accumulated in the skin, but they are also present in the flesh of tubers (Deußer et al., 2012). Their composition is highly dependent on cultivar type and pre- and postharvest impacts like crop maturity, climatic conditions, soil, irrigation, as well as mechanical stress during harvesting and storage conditions after harvesting (Akyol et al., 2016). Chlorogenic acid and its isomers neochlorogenic and cryptochlorogenic acids are predominant phenolic compounds in potato (almost 90%), besides caffeic, ferulic, *p*-coumaric, syringic, and vanillic acid. Catechin, as flavan-3-ol, is a dominant flavonoid, while the presence of epicatechin depends on the cultivar type. Similarly, kaempferol-3-*O*-rutinoside and rutin, as flavonols, were identified only in some potato cultivars (Deußer et al., 2012). Although phenolics' content is much higher in vegetables such as onions and tomatoes, due to the frequent potato consumption, the intake of phenolics by potatoes is not negligible (Blessington et al., 2010). The presence of phenolics in food depends on the cooking method (Andre et al., 2009; Perla et al., 2012), and they can affect the taste, color, and nutritional value of the dish (Perla et al., 2012). Considering the role of phenolics in the unfavorable enzymatic browning reactions, it is important to examine their content during tubers' storage and processing.

Sugars like monosaccharides (glucose and fructose) and disaccharide (sucrose) present in the potatoes are constituents whose content also strongly depends upon the above-mentioned pre- and postharvest factors (Kumar et al., 2004). Storage of potatoes at lower temperature results in the so-called "low-temperature sweetening," a phenomenon of increased sugars' content in potato tissue, which could lead to a darker color, and bitterness and could also contribute to the formation of acrylamide (AA) in fried products (Kumar et. al., 2004). AA is formed as a product of Maillard's reaction by the interactions of reducing sugars (glucose and fructose) and the amino acid asparagine at temperatures above 120°C and low water content. Thus, AA is not generated in boiled or steamed potatoes and its content is lower in French fries than in crisps (Bethke & Bussan, 2013; Paul et al., 2016). AA is considered as a potential carcinogenic compound (Rice, 2005), and according to the EU Commission Regulation 2017/2158 (ECR 2017/2158) the upper limit for AA in potato products is 750 μg kg^{-1} of fresh weight (FW). The common content of asparagine in tubers is in a range from 4 to 25 mg g^{-1} of dry matter (DM), while reducing sugars' content ranges from just below 0.04 to 4.8 mg g^{-1} DM (Bethke & Bussan, 2013). There is some correlation between AA formation during cooking and the content of asparagine and reducing sugars in the tubers. However, the final level of AA depends on many factors. One of them is the type of cultivars, whether they are intended for frying or producing crisps. Since tubers contain a lot more asparagine than reducing sugars, it is more likely that reducing sugars, and not the asparagine, could be a limiting factor in the formation of AA (Bethke &

Bussan, 2013). Therefore, the food industry tends to use potato cultivars that are less prone to accumulating reducing sugars during storage (Elmore et al., 2015). Elmore et al. (2015) and Halford et al. (2011) reported that cultivars Saturna, Lady Rosetta, Lady Claire, and Verdi are suitable for crisps production, while cultivars Markies, Fontane, and Maris Piper are suitable for producing French fries with the AA level below the ECR indicative value. When evaluating cultivars for FCP production, the influence of cultivar on the formation of AA during frying of FCP should also be considered. Potato cultivars differ in the levels of phenolics, and some findings have indicated phenolics' contribution in lower AA level in fried potatoes (Kalita et al., 2013; Zhu et al., 2010).

The goal of this work was to investigate the influence of tubers' age of two potato cultivars (Birgit and Lady Claire) on the content of phenolics and sugars in FCP during 8 days storage. In addition, this work also examined the influence of cooking (boiling and frying) on the content of phenolics and sugars as well as on the AA level in fried samples.

2 | MATERIALS AND METHODS

2.1 | Chemicals, standards, and solutions

Water was of Milli-Q quality (Millipore Corp., Bedford, MA, USA). All organic solvents were of HPLC analytical grade. AA (> 99%), d3-acrylamide, sugar standards D-(−)-fructose (≥99% GC), D-(+)-glucose (≥99.5% GC), and D-(+)-sucrose (≥99.5% GC) were purchased from Sigma Aldrich (Milano, Italy), whereas chlorogenic acid, epicatechin, and catechin were purchased from Extrasynthese (Genay, France).

2.2 | FCP processing

Two potato cultivars, Birgit (German table potato) and Lady Claire (Dutch industrial potato cultivar) grown in Croatia, in the Slavonia region (45°40′N, 17°1′E) during 2017 were used for the experiments. The potatoes treated with antisprouting agents (Gro Stop Basis and Gro Stop Fog, Certis Europe B.V., Great Abington, UK) were stored in a dark warehouse in wooden pallet boxes at 8°C with approximately 100% relative humidity (RH). They were stored at 16 °C for 3 days before processing. After 1, 5, and 9 months of storage, potatoes were taken for processing and analysis. Fresh-cut processing was conducted according to the previously established conditions (Dite Hunjek et al., 2020a;, 2020b): undamaged and uniform tubers with a diameter >35 mm were selected, hand peeled with a knife, and washed by tap water. Afterwards, potatoes were cut with a commercial cutting machine (MCM62020-CNCM30, Multitalent, Robert Bosch d.o.o., Škofja Loka, Slovenia) into 4 mm thick slices, dipped into an antibrowning solution of sodium ascorbate (2%, w v^{-1}) (Nutrimedica d.o.o., Zagreb, Croatia) for 3 min at 18°C with sample/solution (g mL^{-1}) ratio 1:4 and drained. Only unharmed and uniform slices (200 g) were vacuum packaged (WS110W vacuum packager, Gorenje, Velenje, Slovenia) in polyamide/polyethylene (PA/PE) bags with a film thickness of 90 μm (permeability at 23 °C and RH 0% for O_2 was 8.21 cm^3 $m^{-2}day^{-1}$ bar^{-1}, for CO_2 was 45.1 cm^3 m^{-2} day^{-1} bar^{-1} and for N_2 23 cm^3 m^{-2} day^{-1} bar^{-1}), stored at 10°C and analyzed at the beginning (0) and after 5 and 8 days of storage.

2.3 | Boiling and frying

Cooking of FCP included boiling and frying by the procedure described by Dite Hunjek et al. (2020a, 2020b): for boiled FCP, samples (50 g) were boiled in water [sample: water (g mL^{-1}) = 1:5] for 15 min and drained. Fried FCP was prepared by frying the slices (150 g) in 1.5 L of sunflower oil (Zvijezda d.d., Zagreb, Croatia) using the commercial fryer (FR490070, Tefal, Rumilly, France) at 180 °C for 5 min. After frying, samples were put on a paper towel for excess oil absorption.

For further analysis, samples of raw, boiled, and fried FCP were freeze-dried (CoolSafe PRO, Labogene, Denmark) for 24 hr. The entire sample (all slices in a bag) was divided into three lots: one lot was immediately freeze-dried, the second one was boiled and then freeze-dried, and the third one was fried and freeze-dried. All freeze-dried samples were ground and from obtained homogenized powder two extractions were performed for each sample ($n = 2$).

2.4 | Phenolics analysis

2.4.1 | Extraction of phenolics

The freeze-dried samples (0.5 g) were mixed with 5 mL of 80% methanol with 1% formic acid (v v^{-1}), sonicated in an ultrasonic bath (Elmasonic 40H, Elma, Germany) for 30 min at 50 °C (with occasional vortex mixing) and centrifuged at 1106.82 × g/10 min. Another 5 mL of an extraction solvent was added again to the precipitate and the procedure was repeated. Subsequently, the resulting supernatants were combined, filtered into a 10 mL flask, and made up with the solvent. Obtained extract (1 mL) was filtered through a 0.45 μm filter before the ultra-performance

liquid chromatography-tandem mass spectrometer (UPLC MS^2) analysis.

2.4.2 | UPLC MS^2 analysis of phenolics

The solvent composition and the gradient conditions for the determination of individual phenolic compounds were carried out according to the method reported by Elez Garofulić et al. (2018). Ultra-performance liquid chromatography (UPLC) analyses were performed on an Agilent 1290 RRLC instrument (Agilent Technologies, Santa Clara, CA, USA) coupled to binary a gradient pump, autosampler, and column compartment. Before the injecting, the extracts were filtered through a 0.45-mm membrane filter. The column used for the separation was a Zorbax Eclipse Plus C18 column (100 × 2.1 mm, 1.8 μm) (Agilent, Santa Clara, CA, USA). The ionization was done by electrospray (ESI) in the positive and negative modes (*m/z* 100 to 1000), and a mass spectrometer (QQQ 6430, Agilent, Santa Clara, CA, USA) was used in the dynamic multiple reaction monitoring mode (dMRM) and operated with the following source parameters: capillary voltage, +4000/-3500 V, nitrogen drying gas temperature was maintained at 300 °C with a flow rate of 11 L h^{-1}, and the pressure of nebulizer was set at 40 psi. MassHunter software was used for the data acquisition and analysis. The external standard method of the calibration was applied. Identification of the phenolics was carried out by comparing the retention times and mass spectra with those of authentic standards. Individual phenolics, as well as their sum (total phenolics) were expressed as mg 100 g^{-1} DW.

2.5 | Sugar analysis

2.5.1 | Extraction of sugars

Sugars were extracted following the method described by Duarte-Delgado et al. (2015) with some modifications. Briefly, freeze-dried samples (0.4 g) were homogenized with 4 mL of 80% methanol by vortex (VELP Scientifica, Usmate, Italy). Afterwards, the mixture was heated in a water bath at 60 °C for 60 min and occasionally mixed with vortex. The mixture was then centrifuged (Hettich® Rotofix 32a, Tuttlingen, Germany) at 4427.28 × g/15 min. The supernatant was filtered into a 5 mL flask and made up with the solvent.

2.5.2 | High-performance liquid chromatography analysis of sugars

The determination of sugars was based on the method described by Sesta (2006) with slight modification. Chromatographic separation was performed using high-performance liquid chromatography (HPLC) analysis with an Agilent 1260 Infinity quaternary LC system (Agilent Technologies) equipped with a refractive index detector, an automatic injector, and ChemStation software. The separation of sugars was performed on the Cosmosil Sugar-D 4.6 IDX250 mm column (Nacalai Tesque, INC., Kyoto, Japan). The mobile phase was 80% acetonitrile. The isocratic method ran at a flow rate of 1 mL min^{-1} at a column temperature of 45 °C. Prior to injection, extracts were filtered through a 0.45-mm membrane filter (Macherey-Nagel GmbH & Co. KG, Düren, Germany). The peaks were identified by comparing their retention times with the standard compounds, and quantification of sugars was performed by standardization with the external standards. All standards were prepared as stock solutions in ethanol (10 mg mL^{-1}) and diluted to five concentrations in a range from 0.05 to 5 mg mL^{-1}. The results of individual sugars and their sum (total sugars) were expressed as g 100 g^{-1} DW.

2.6 | Acrylamide analysis

2.6.1 | Extraction of acrylamide

AA was determined in fried FCP samples. The extraction procedure and chromatographic method were performed according to Rosén et al. (2007) with few modifications. A mixture of 400 μL of an internal d3-acrylamide standard solution (1000 ng mL^{-1}), 40 mL of water, and 2.0 g of freeze-dried sample was manually mixed (15 to 30 s), vortexed for about 15 s, and then stirred for 60 min. The extract was then cooled to +4 °C for 10 min and centrifuged (1593.82 × g/20 min). The supernatant (10 mL) was used for purification performed by solid-phase extraction (SPE) clean-up procedures using Isolute Multimode (1 g, 6 mL) and Isolute Env+ (0.5 g, 6 mL) SPE columns (IST, Hengoed, Mid Glamorgan, UK). Afterwards, the extract was evaporated at 30 °C (Eppendorf Concentrator Plus, Fisher Scientific, Leicestershire, England, UK) to a volume of approximately 500 μL, filtered through a 0.45-mm membrane filter and analyzed by UPLC MS^2.

2.6.2 | UPLC MS^2 analysis of acrylamide

Samples were analyzed by the Agilent UPLC system equipped as previously described in Section 2.4.2 with an electrospray ion source in positive ion mode. The column used for separation was Hypercarb TM (5 μm, 50 mm × 2.1 mm) with a guard column (5 μm, 10 mm × 2 mm) (Thermo Hypersil-Keystone, Bellefonte, PA, USA). The identification of AA was confirmed by comparing the peak ratios of MRM transitions *m/z* 54/55 and 44/55 from sample extracts and standard solutions, and quantification was performed using a calibration of internal d3-acrylamide and AA standards. The results were expressed as μg kg^{-1} DW.

2.7 | Statistical analysis

The experiment was designed as a full factorial randomized experimental design and experimental data were analyzed using Statistica ver. 12.0 software (Statsoft Inc., Tulsa, OK, USA). Results are expressed as mean ± standard error (SE). After testing data for normality by the Shapiro–Wilk test and homoscedasticity by Levene's test, the influence of cultivar (Birgit and Lady Claire), tubers' age (1, 5, and 9 months), FCP storage time (0, 5, and 8 days), and cooking method (raw, boiled, and fried FCP) on the content of catechin, epicatechin, chlorogenic acid, total phenolics, fructose, glucose, sucrose, and total sugars were examined using ANOVA (parametric data) or Kruskal–Wallis test (nonparametric data) and means within groups were compared with Tukey's HSD test or Kruskal—Wallis test (Granato et al., 2014). The same statistical procedure was also applied to test the influence of cultivar, tubers' age, and FCP storage time on the AA level in fried FCP. For the examination of possible grouping of samples according to the applied sources of variation (cultivar, tubers' age, storage time, and cooking method), principal component analysis (PCA) was applied on a correlation matrix of 54 samples using catechin, epicatechin, chlorogenic acid, total phenolics, fructose, glucose, sucrose, and total sugars values (a total of 432 data points). Principal components (PC) with eigenvalue > 1 were considered and variables with communalities ≥0.5 were included in the test (de Araujo Moretti et al., 2019; Hair et al., 2009). Prior to PCA, data were autoscaled. The relationship between sugars and AA was tested by calculated Spearman's rank correlation coefficients. The significance level of $p < 0.05$ was assigned to all tests.

3 | RESULTS AND DISCUSSION

3.1 | Phenolics analysis

Table 1 presents the results of identified phenolic compounds, namely chlorogenic acid, catechin, epicatechin, and total phenolics' content. Chlorogenic acid was the predominant phenol [grand mean value (GM) 7.46 mg 100 g^{-1} DW], while catechin was present in the lowest concentrations (GM 0.170 mg 100 g^{-1} DW). The GM of 0.318 mg 100 g^{-1} DW described the presence of epicatechin, while the GM of 7.95 mg 100 g^{-1} DW accounted for total phenolics. Akyol et al. (2016), Deuβer et al. (2012), and Navarre et al. (2011) also noted that chlorogenic acid was a dominant phenolic compound in potato as well as that the presence of catechin was in a remarkably lower level, while epicatechin was identified just in certain cultivars. Potato also includes other phenolic compounds, whose presence and amounts vary among cultivars (Deuβer et al., 2012). In this research, the differences between cultivars were also noticed. Higher content of almost all phenolics was determined in cv. Lady Claire (chlorogenic acid 9.63 mg 100 g^{-1} DW, epicatechin 0.337 mg 100 g^{-1} DW, catechin 0.168 mg 100 g^{-1} DW, and total phenolics 10.13 mg 100 g^{-1} DW) versus cv. Birgit (chlorogenic acid 5.30 mg 100 g^{-1} DW, epicatechin 0.298 mg 100 g^{-1} DW, catechin 0.172 mg 100 g^{-1} DW, and total phenolics 5.77 mg 100 g^{-1} DW). Values obtained for both cultivars were generally consistent with the results of Deuβer et al. (2012). A significant impact of cultivar was observed on the chlorogenic acid and total phenolics content. Content of all phenolics significantly decreased during tubers' aging (Table 1), although the lowest content was determined in the fifth month (approximately 25% retained when compared to the first month). Even though there was an increase in the last storage period (for about 50% when compared to the fifth month), the content of chlorogenic acid and total phenolics was almost threefold lower than at the beginning of the storage. This was the case for both cultivars, with less lowering observed in cv. Birgit, although it contained less phenolics (Table 1). Several authors (Akyol et al., 2016; Blessington et al., 2010; Külen et al., 2013) found that phenolics' content in potato during long-term storage was dependent on the type of cultivar as well as storage time and temperature. Akyol et al. (2016) gave an overview about the content of phenolics during storage and reported that phenolics' content increased or stayed the same during the cold storage (4 °C) of potatoes, while Andre et al. (2009) reported that phenolics' content decreased or stayed the same during the storage at 10°C. Külen et al.

TABLE 1 The influence of cultivar, tubers' age, cold storage, and cooking on phenolics (mg 100 g^{-1} DW) and sugars (g 100 g^{-1} DW) in fresh-cut potato

Source of variation	Catechin	Epicatechin	Chlorogenic acid	Total phenolics	Fructose	Glucose	Sucrose	Total sugars
Cultivar								
	$p = 0.722$	$p = 0.658$	$p = 0.006$*	$p = 0.009$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit	0.172 ± 0.008a	0.298 ± 0.044a	5.30 ± 0.40a	5.77 ± 0.44a	0.321 ± 0.023b	0.373 ± 0.024b	1.06 ± 0.13b	1.75 ± 0.16b
Lady Claire	0.168 ± 0.008a	0.337 ± 0.054a	9.63 ± 1.20b	10.13 ± 1.24b	0.140 ± 0.017a	0.178 ± 0.030a	0.33 ± 0.02a	0.65 ± 0.05a
Tubers' age (month)								
	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
1	0.213 ± 0.008b	0.725 ± 0.060b	13.67 ± 1.47c	14.61 ± 1.49c	0.099 ± 0.009a	0.136 ± 0.010a	0.38 ± 0.04a	0.61 ± 0.06a
5	0.131 ± 0.012a	0.120 ± 0.017a	3.45 ± 0.24a	3.70 ± 0.25a	0.241 ± 0.027b	0.294 ± 0.028b	0.37 ± 0.02a	0.91 ± 0.08b
9	0.167 ± 0.001a	0.109 ± 0.007a	5.28 ± 0.28b	5.55 ± 0.28b	0.351 ± 0.029b	0.396 ± 0.049b	1.33 ± 0.17b	2.08 ± 0.21c
Storage (day)								
	$p = 0.466$	$p = 0.758$	$p = 0.778$	$p = 0.858$	$p = 0.567$	$p = 0.655$	$p = 0.805$	$p = 0.849$
0	0.174 ± 0.013a	0.358 ± 0.066a	9.53 ± 1.66a	10.06 ± 1.71a	0.226 ± 0.023a	0.289 ± 0.047a	0.76 ± 0.17a	1.27 ± 0.20a
5	0.171 ± 0.008a	0.308 ± 0.059a	6.82 ± 0.84a	7.30 ± 0.88a	0.219 ± 0.032a	0.256 ± 0.032a	0.66 ± 0.12a	1.14 ± 0.16a
8	0.166 ± 0.008a	0.287 ± 0.057a	6.04 ± 0.60a	6.49 ± 0.65a	0.246 ± 0.032a	0.281 ± 0.031a	0.66 ± 0.09a	1.19 ± 0.15a
Cooking method								
	$p = 0.037$*	$p < 0.001$*	$p = 0.001$*	$p = 0.001$*	$p = 0.479$	$p = 0.126$	$p = 0.050$	$p = 0.107$
Raw	0.194 ± 0.009a	0.361 ± 0.053b	9.52 ± 1.25b	10.08 ± 1.28b	0.243 ± 0.032a	0.306 ± 0.034a	0.86 ± 0.17a	1.41 ± 0.21a
Boiled	0.144 ± 0.011a	0.127 ± 0.026a	5.75 ± 0.91a	6.02 ± 0.93a	0.210 ± 0.027a	0.268 ± 0.050a	0.51 ± 0.08a	0.99 ± 0.14a
Fried	0.173 ± 0.008a	0.465 ± 0.077b	7.12 ± 1.19ab	7.76 ± 1.25ab	0.238 ± 0.028a	0.252 ± 0.024a	0.71 ± 0.11a	1.20 ± 0.15a
Cultivar × tubers' age (month)								
	$p = 1.000$	$p = 0.411$	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit × 1	0.215 ± 0.012a	0.677 ± 0.069a	8.42 ± 0.58a	9.31 ± 0.63a	0.132 ± 0.014b	0.174 ± 0.013b	0.54 ± 0.07b	0.85 ± 0.08b
Lady Claire × 1	0.210 ± 0.009a	0.773 ± 0.100a	18.93 ± 2.31b	19.91 ± 2.34b	0.065 ± 0.005a	0.099 ± 0.008a	0.21 ± 0.02a	0.37 ± 0.03a
	$p = 0.656$	$p = 0.514$	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit × 5	0.135 ± 0.018a	0.132 ± 0.023a	2.79 ± 0.27a	3.06 ± 0.29a	0.370 ± 0.031b	0.417 ± 0.035b	0.48 ± 0.03b	1.26 ± 0.09b
Lady Claire × 5	0.127 ± 0.017a	0.108 ± 0.024a	4.10 ± 0.33b	4.34 ± 0.35b	0.112 ± 0.010a	0.171 ± 0.012a	0.27 ± 0.02a	0.55 ± 0.02a
	$p = 0.505$	$p < 0.001$*	$p = 0.062$	$p = 0.003$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit × 9	0.167 ± 0.001a	0.086 ± 0.007a	4.70 ± 0.32a	4.95 ± 0.32a	0.460 ± 0.024b	0.528 ± 0.013b	2.16 ± 0.20b	3.15 ± 0.19b
Lady Claire × 9	0.167 ± 0.001a	0.131 ± 0.007b	5.85 ± 0.42a	6.15 ± 0.42b	0.242 ± 0.039a	0.264 ± 0.088a	0.51 0.02a	1.02 ± 0.11a
Cultivar × storage (day)								
	$p = 0.924$	$p = 0.681$	$p = 0.164$	$p = 0.242$	$p = 0.023$*	$p = 0.001$*	$p = 0.009$*	$p = 0.002$*
Birgit × 0	0.178 ± 0.020a	0.361 ± 0.094a	5.59 ± 0.69a	6.13 ± 0.78a	0.278 ± 0.028b	0.339 ± 0.033b	1.16 ± 0.30b	1.78 ± 0.34b
Lady Claire × 0	0.171 ± 0.017a	0.355 ± 0.095a	13.47 ± 3.00a	14.00 ± 3.09a	0.174 ± 0.033a	0.240 ± 0.088a	0.36 ± 0.03a	0.77 ± 0.13a

(Continues)

TABLE 1 (Continued)

Source of variation	Catechin	Epicatechin	Chlorogenic acid	Total phenolics	Fructose	Glucose	Sucrose	Totalsugars
	$p = 0.229$	$p = 0.326$	$p = 0.018$*	$p p = 0.034$*	p < 0.001*	p < 0.001*	p = 0.001*	p < 0.001*
Birgit × 5	0.184 ± 0.005a	0.273 ± 0.073a	4.99 ± 0.61a	5.45 ± 0.68a	0.339 ± 0.040b	0.385 ± 0.044b	0.98 ± 0.20b	1.71 ± 0.26b
Lady Claire × 5	0.158 ± 0.014a	0.342 ± 0.093a	8.66 ± 1.47b	9.16 ± 1.53b	0.100 ± 0.029a	0.128 ± 0.017a	0.34 ± 0.04a	0.57 ± 0.06a
Cultivar × storage (day)								
	$p = 0.580$	$p = 0.727$	$p = 0.155$	$p = 0.195$	$p = 0.004$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit × 8	0.156 ± 0.014a	0.260 ± 0.059a	5.33 ± 0.79a	5.74 ± 0.85a	0.345 ± 0.050b	0.395 ± 0.048b	1.03 ± 0.13b	1.77 ± 0.21b
Lady Claire × 8	0.176 ± 0.006a	0.314 ± 0.098a	6.75 ± 0.90a	7.24 ± 0.98a	0.147 ± 0.024a	0.166 ± 0.015a	0.29 ± 0.04a	0.60 ± 0.06a
Cultivar × cooking method								
	$p = 0.728$	$p = 0.129$	$p = 0.054$	$p = 0.050$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit × raw	0.200 ± 0.014a	0.350 ± 0.083a	6.73 ± 0.73a	7.28 ± 0.79a	0.362 ± 0.047b	0.435 ± 0.048b	1.36 ± 0.30b	2.15 ± 0.34b
Lady Claire × raw	0.189 ± 0.010a	0.372 ± 0.068a	12.32 ± 2.22a	12.88 ± 2.29b	0.124 ± 0.022a	0.178 ± 0.021a	0.37 ± 0.04a	0.67 ± 0.06a
	$p = 0.495$	$p = 0.949$	$p = 0.046$*	$p = 0.058$	$p = 0.002$*	$p = 0.002$*	$p < 0.001$*	$p = 0.001$*
Birgit × boiled	0.139 ± 0.019a	0.135 ± 0.042a	3.96 ± 0.51a	4.24 ± 0.56a	0.286 ± 0.036b	0.330 ± 0.043b	0.75 ± 0.14b	1.37 ± 0.20b
Lady Claire × boiled	0.149 ± 0.013a	0.119 ± 0.032a	7.53 ± 1.67b	7.80 ± 1.71a	0.134 ± 0.032a	0.205 ± 0.089a	0.26 ± 0.04a	0.60 ± 0.13a
	$p = 0.825$	$p = 0.800$	$p = 0.229$	$p = 0.146$	$p = 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*
Birgit × fried	0.178 ± 0.004a	0.410 ± 0.084a	5.22 ± 0.69a	5.81 ± 0.76a	0.314 ± 0.038b	0.354 ± 0.030	1.07 ± 0.8b	1.74 ± 0.23b
Lady Claire × fried	0.167 ± 0.016a	0.520 ± 0.130a	9.02 ± 2.22a	9.71 ± 2.32a	0.162 ± 0.034a	0.150 ± 0.014	0.35 ± 0.03a	0.66 ± 0.07a
Storage (day) × tubers' age (month)								
	$p = 0.019$*	$p = 0.273$	$p = 0.058$	$p = 0.069$	$p = 0.879$	$p = 0.723$	$p = 0.854$	$p = 0.868$
0 × 1	0.246 ± 0.016b	0.843 ± 0.093a	19.76 ± 3.33a	20.85 ± 3.34a	0.103 ± 0.021a	0.124 ± 0.014a	0.29 ± 0.02a	0.52 ± 0.05a
5 × 1	0.196 ± 0.007ab	0.677 ± 0.113a	11.59 ± 1.79a	12.46 ± 1.82a	0.100 ± 0.015a	0.142 ± 0.018a	0.35 ± 0.05a	0.59 ± 0.09a
8 × 1	0.196 ± 0.009a	0.654 ± 0.106a	9.66 ± 1.09a	10.51 ± 1.15a	0.093 ± 0.011a	0.144 ± 0.020a	0.48 ± 0.12a	0.72 ± 0.14a
	$p = 0.095$	$p = 0.158$	$p = 0.312$	$p = 0.245$	$p = 0.531$	$p = 0.712$	$p = 0.739$	$p = 0.934$
0 × 5	0.109 ± 0.023a	0.126 ± 0.028a	2.88 ± 0.23a	3.12 ± 0.23a	0.231 ± 0.039a	0.275 ± 0.033a	0.34 ± 0.02a	0.85 ± 0.09a
5 × 5	0.149 ± 0.021a	0.144 ± 0.031a	3.76 ± 0.36a	4.06 ± 0.37a	0.231 ± 0.055a	0.281 ± 0.054a	0.37 ± 0.03a	0.88 ± 0.14a
8 × 5	0.137 ± 0.019a	0.089 ± 0.028a	3.69 ± 0.57a	3.91 ± 0.59a	0.262 ± 0.049a	0.326 ± 0.057a	0.40 ± 0.06a	0.99 ± 0.16a
	$p = 0.002$*	$p < 0.001$*	$p = 0.296$	$p = 0.033$*	$p = 0.550$	$p = 0.931$	$p = 0.587$	$p = 0.490$
0 × 9	0.168 ± 0.002b	0.106 ± 0.012b	5.94 ± 0.54a	6.22 ± 0.54b	0.344 ± 0.021a	0.469 ± 0.121a	1.64 ± 0.39a	2.45 ± 0.42a
5 × 9	0.168 ± 0.001b	0.101 ± 0.015a	5.12 ± 0.54a	5.39 ± 0.55ab	0.326 ± 0.063a	0.347 ± 0.066a	1.26 ± 0.27a	1.93 ± 0.37a
8 × 9	0.165 ± 0.001a	0.118 ± 0.012c	4.76 ± 0.28a	5.05 ± 0.29a	0.383 ± 0.059a	0.373 ± 0.056a	1.10 ± 0.20a	1.86 ± 0.30a

(Continues)

TABLE 1 (Continued)

Source of variation	Catechin	Epicatechin	Chlorogenic acid	Total phenolics	Fructose	Glucose	Sucrose	Total sugars
Cooking method × tubers' age (month)								
	$p < 0.001$*	$p < 0.001$*	$p = 0.074$	$p = 0.023$*	$p = 0.095$	$p = 0.002$*	$p = 0.142$	$p = 0.049$*
Raw × 1	0.251 ± 0.015b	0.780 ± 0.047b	16.97 ± 2.59a	18.00 ± 2.57b	0.096 ± 0.012a	0.159 ± 0.016b	0.47 ± 0.09a	0.72 ± 0.11a
Boiled × 1	0.176 ± 0.006a	0.315 ± 0.038a	10.56 ± 2.12a	11.05 ± 2.13a	0.090 ± 0.022a	0.094 ± 0.013a	0.22 ± 0.03a	0.41 ± 0.06a
Fried × 1	0.211 ± 0.005b	1.079 ± 0.064b	13.48 ± 2.77a	14.77 ± 2.81ab	0.110 ± 0.012a	0.157 ± 0.016b	0.44 ± 0.08a	0.70 ± 0.11a
	$p = 0.334$	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p = 0.560$	$p = 0.081$	$p < 0.001$*	$p = 0.271$
Raw × 5	0.168 ± 0.005a	0.179 ± 0.010b	4.77 ± 0.39c	5.11 ± 0.38c	0.298 ± 0.059a	0.388 ± 0.060a	0.42 ± 0.05c	1.10 ± 0.17a
Boiled × 5	0.089 ± 0.027a	0.000 ± 0.000a	2.52 ± 0.27a	2.61 ± 0.28a	0.208 ± 0.038a	0.235 ± 0.038a	0.32 ± 0.04a	0.76 ± 0.11a
Fried × 5	0.138 ± 0.019a	0.181 ± 0.025b	3.05 ± 0.27b	3.37 ± 0.26b	0.218 ± 0.041a	0.259 ± 0.033a	0.38 ± 0.02b	0.86 ± 0.09a
Cooking method × tubers' age (month								
	$p = 0.057$	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p = 0.323$	$p = 0.742$	$p = 0.184$	$p = 0.456$
Raw × 9	0.164 ± 0.001a	0.125 ± 0.014b	6.84 ± 0.46b	7.12 ± 0.46b	0.336 ± 0.059a	0.373 ± 0.063a	1.71 ± 0.41a	2.42 ± 0.49a
Boiled × 9	0.168 ± 0.001a	0.067 ± 0.006a	4.16 ± 0.30a	4.39 ± 0.30a	0.331 ± 0.049a	0.475 ± 0.125a	0.98 ± 0.18a	1.79 ± 0.26a
Fried × 9	0.169 ± 0.002a	0.135 ± 0.007b	4.83 ± 0.28a	5.14 ± 0.28a	0.387 ± 0.046a	0.341 ± 0.050a	1.31 ± 0.24a	2.04 ± 0.32a
Cooking method × storage (day)								
	$p = 0.564$	$p = 0.046$*	$p = 0.508$	$p = 0.425$	$p = 0.310$	$p = 0.564$	$p = 0.675$	$p = 0.872$
Raw × 0	0.213 ± 0.022a	0.398 ± 0.114a	10.62 ± 2.97a	11.23 ± 3.04a	0.221 ± 0.040a	0.259 ± 0.049a	1.01 ± 0.42a	1.49 ± 0.48a
Boiled × 0	0.123 ± 0.027a	0.186 ± 0.065a	8.14 ± 2.45a	8.45 ± 2.50a	0.278 ± 0.046a	0.388 ± 0.127a	0.61 ± 0.19a	1.27 ± 0.27a
Fried × 0	0.186 ± 0.008a	0.492 ± 0.141a	9.82 ± 3.32a	10.50 ± 3.45a	0.180 ± 0.029a	0.221 ± 0.039a	0.66 ± 0.19a	1.07 ± 025a
	$p = 0.068$	$p = 0.008$*	$p = 0.108$	$p = 0.064$	$p = 0.354$	$p = 0.134$	$p = 0.063$	$p = 0.078$
Raw × 5	0.186 ± 0.006a	0.337 ± 0.073b	9.29 ± 2.06a	9.81 ± 2.12a	0.229 ± 0.061a	0.304 ± 0.058a	0.86 ± 0.26a	1.40 ± 0.35a
Boiled × 5	0.171 ± 0.004a	0.096 ± 0.030a	4.97 ± 0.82a	5.24 ± 0.85a	0.164 ± 0.045a	0.192 ± 0.058a	0.40 ± 0.09a	0.76 ± 0.19a
Fried × 5	0.156 ± 0.022a	0.490 ± 0.139b	6.21 ± 0.99a	6.86 ± 1.13a	0.264 ± 0.058a	0.274 ± 0.048a	0.72 ± 0.20a	1.26 ± 0.28a
	$p = 0.234$	$p = 0.053$	$p = 0.008$*	$p = 0.010$*	$p = 0.423$	$p = 0.226$	$p = 0.442$	$p = 0.269$
Raw × 8	0.184 ± 0.010a	0.349 ± 0.090a	8.66 ± 1.24b	9.19 ± 1.34b	0.280 ± 0.067a	0.356 ± 0.068a	0.72 ± 0.15a	1.36 ± 0.26a
Boiled × 8	0.138 ± 0.019a	0.100 ± 0.029a	4.12 ± 0.67a	4.36 ± 0.70a	0.188 ± 0.045a	0.224 ± 0.050a	0.52 ± 0.14a	0.93 ± 0.23a
Fried × 8	0.176 ± 0.004a	0.413 ± 0.129a	5.33 ± 0.67ab	5.92 ± 0.80ab	0.270 ± 0.053a	0.262 ± 0.039a	0.74 ± 0.19a	1.28 ± 0.27a
Grand mean	0.170	0.318	7.46	7.95	0.230	0.276	0.69	1.20

*Results are significant at $p < 0.05$.

Results are expressed as mean ± SE.

Values with different letters within the column are statistically different at $p < 0.05$.

(2013) described that the content of phenolics decreased immediately after harvesting, but increased again throughout the whole cold storage period. An elevation of total soluble phenolics could be linked to the increase of respiration (de Oliveira Silva et al., 2012). Although there was no statistical significance, all phenolics decreased during FCP storage, possibly due to the enzymatic reactions in which they participate (Licciardello et al., 2018). Namely, phenolics, particularly chlorogenic acid, are a substrate for browning reactions in the potato which are catalyzed by enzymes such as peroxidase, catalase, and polyphenol oxidase (Amaki et al., 2011; Li et al., 2018; Narváez-Cuenca et al., 2013). Furthermore, a distinction among cultivars was obvious when observing the interactions of cultivar versus FCP storage time. Even though a decrease in phenolics was observed for both cultivars, the decrease was more pronounced in cv. Lady Claire which was more prone to browning (Dite Hunjek et al., 2020a, 2020b). The interactions of FCP storage time versus tuber's age revealed the different pattern of changes with tuber's storage period. Phenolics mostly decreased during 8 days of storage in FCP produced from tubers which were 1 month and 9 months old. However, for FCP produced from tubers which were 5 months old, phenolics increased by the fifth day of storage. Potato tubers are going through various phases after harvesting and during storage, and a lot of different biochemical processes occur. These processes could have an impact on respiration (Wustman & Struik, 2007) and the activity of various enzymes like phenylalanine ammonia-lyase, a crucial enzyme in the synthesis of phenolics (Maldonado et al., 2007).

The cooking method significantly influenced the phenolics. The content of phenolics was the highest in raw potatoes, with an exception of epicatechin, while their lowest amounts were recorded in boiled FCP (about 40% lower in boiled and 25% in fried when compared to raw). Blessington et al. (2010) also recorded the lowest level of total phenolics in boiled potatoes when compared to baked, fried, and microwaved samples. High temperature during boiling leads to the cell degradation and facilitates liberation of phenolics, and consequently their solubilization in boiling water (Tian et al., 2016). The interaction of cultivar versus the cooking method showed the same pattern in both cultivars as for the cooking method by itself. Even though the majority of the highest values were present in cv. Lady Claire samples, only total phenolics in raw samples and chlorogenic acid in boiled samples were significantly higher. The interaction of the cooking method versus tubers' age and cooking method versus FCP storage followed the same trend as it was previously discussed for individual impacts. Fried potatoes contained more phenolics in comparison with the boiled ones, which is in accordance with the results of Blessington et al. (2010), although in their study higher phenolics content was reported in cooked samples than in uncooked. Accordingly, Perla et al. (2012) deduced that the literature data give contradictory results with regard to the impact of domestic cooking on phenolic compounds. In addition to the cooking conditions, many other factors, such as structure, solubility, mutual linking, selective leaching, oxidative enzyme inactivation, and protective effect of chlorogenic acid on rutin, could affect the phenolics' content in cooked potato (Perla et. al., 2012).

3.2 | Sugar analysis

The results obtained for glucose, fructose, sucrose, as well as total sugars are shown in Table 1. As it can be seen, sucrose was the most abundant sugar (GM 0.69 g 100 g^{-1} DW), followed by glucose (GM 0.276 g 100 g^{-1} DW) and fructose (GM 0.230 g 100 g^{-1} DW), while average total sugar in all samples was 1.20 g 100 g^{-1} DW. The type of cultivar and tubers' age significantly influenced the content of all determined sugars. In both examined cultivars (Birgit and Lady Claire), there was a higher level of sucrose (1.06 and 0.33 g 100 g^{-1} DW, respectively) in comparison to glucose (0.373 and 0.178 g 100 g^{-1} DW, respectively) and fructose (0.321 and 0.140 g 100 g^{-1} DW, respectively). All individual sugars and the total sugars content were higher in cv. Birgit when compared to cv. Lady Claire. It is well known, and supported by numerous studies, that the content of sugars and their distribution in potatoes varies greatly with the type of cultivar, ranging from < 1 to several percentages (Amrein et al., 2003; Duarte-Delgado et al., 2015; Zhu et al., 2010). This is due to different breeding processes designed to produce cultivars adequate for various utilization, for example, cold storage and crisps production (Wayumba et al., 2019). Cv. Birgit is a table cultivar (Norika GmbH, 2020), while Lady Claire is an industrial crisps cultivar (which implies low and pretty stable sugar level during long-term storage) (Elmore et al., 2015; Muttucumaru et al., 2014; Potato Variety Database, 2020). Our results for sugars content in cv. Lady Claire were consistent with the results of Elmore et al. (2015), just slightly higher. Variations among the same cultivar were already reported (Elmore et al., 2015; Muttucumaru et al., 2014). Still, the results in the present research revealed that both cultivars had a remarkably low content of sugars.

Individual sugars as well as total sugars content increased in both cultivars with the age of tubers. An increase was higher in cv. Birgit in comparison with cv. Lady Claire, and the maximum values were around 3 and 1 g 100 g^{-1} DW (cultivar vs. tubers' age), respectively. Elmore et al. (2015) and Muttucumaru et al. (2014) reported the decrease in reducing sugars during storage of cv. Lady

Claire, while in crisps cultivar Lady Rosetta and all French fry cultivars reducing sugars increased. An increase in sugars during long-term storage at lower temperatures, the so-called "low-temperature sweetening" (Kumar et al., 2004), occurs as a result of starch degradation by enzymes (Halford et al., 2011). Additionally, long-term storage has been causing other phenomenon, "senescent sweetening," which is, unlike cold sweetening, generally irreversible (Kumar et al., 2004). Observed increased sugars were probably a consequence of both sweetening types. However, there was no significant influence of FCP storage on sugars' content. The results for each cultivar individually showed a slight increase of glucose and fructose as well as the decrease of sucrose in cv. Birgit, which was probably due to the invertase activity. Nevertheless, the content of total sugars remained unchanged and cv. Birgit retained significantly higher sugars' values throughout the whole FCP storage period. In cv. Lady Claire, all sugars showed a slight decrease, presumably due to the activity of invertase and other enzymes of sugar metabolism (Halford et al., 2011). Further, no significant influence on all analyzed sugars was shown during storage of FCP produced from different tubers' age. Still, sugars slightly increased during storage of FCP produced from 1 and 5 months old tubers, while they slightly decreased in FCP produced from 9-month-old tubers. Such phenomenon could be linked to starch metabolism and likely to tubers' senescence occurring toward the end of tubers' storage (Kumar et al., 2004).

When observing all samples, there was no significant influence of the cooking method on analyzed sugars. However, there were significant differences between cultivars within each cooking method. Generally, raw potatoes of both cultivars had the highest content of total sugars, while boiled potatoes were characterized by the lowest total sugars' levels. With regard to cooked FCP, cv. Birgit had almost two- to threefold higher values for total sugars than cv. Lady Claire. During cooking, cell walls break, and that causes the release of sugars from the cells (Pedreschi et al., 2009; Zhang et al., 2018). During boiling, further losses occur due to the solubility of sugars in water. We observed that during frying sugars decreased as well, due to the involvement of sugars in Maillard's reactions. In these reactions, sugars interact with amino acids and consequently form the compounds that cause a brown color as well as characteristic odor and taste of the fried potato (Halford et al., 2011; Jansky, 2010). However, the formation of harmful carcinogenic compounds such as AA can also arise during frying (Halford et al., 2011; Zhu et al., 2010). The AA formation is a consequence of complex reactions, and it depends on many factors, such as potato traits and frying conditions like temperature and time (Pedreschi et al., 2004). The data collected for the cooking method versus tuber's age as well as the cooking method versus FCP storage did not show a significant influence on the content of individual sugars and total sugars. With an increase in tubers' age, sugars increased in raw, boiled, and fried samples. FCP storage also led to the increase of reducing sugars in raw and fried samples, whereas their amount slightly decreased in boiled samples. Still, these alterations were numerically negligible.

3.3 | PCA analysis

PCA was additionally performed in order to test whether the FCP samples will separate by analyzed phenolics and sugars according to the applied sources of variation. PCA did not provide a separation of the samples by the effect of FCP storage time, thus the results are not shown. Obtained biplots in relation to the cultivar type, tubers' age, and cooking method are shown in Figures 1–3. It can be seen that the total variation of the analytical parameters is explained with 78.49% of the total variance and is presented by the first two principal components (PC1 and PC2). The PC1 attributed to 52.85% of total variance, and it moderately correlated with catechin ($r = 0.46$), strongly correlated with epicatechin ($r = 0.72$), chlorogenic acid ($r = 0.74$), total phenolics ($r = 0.75$), sucrose ($r = -0.66$), and total sugars ($r = -0.79$), while a very strong correlation described its relationship with fructose ($r = -0.83$) and glucose ($r = -0.80$). The PC2 accounted for 25.64% of the total variance, and it showed a weak correlation with fructose ($r = 0.33$) and glucose ($r = 0.36$) as well as a moderate correlation with the rest of analyzed parameters ($r = 0.42$-0.59). Visually, considering the cultivar type, almost all cv. Birgit samples were situated at negative values of PC1, and they were described with higher content of sugars. The majority of cv. Lady Claire potatoes, containing higher levels of phenolics, were placed at positive PC1 values (Figure 1). As for tubers' age, samples produced from 1-month-old tubers were clearly distinguished from the samples produced from older tubers. Certain separation was also present between the samples produced from 5- and 9-month-old tubers. Therefore, samples produced from 1-month-old tubers were characterized by higher values of phenolics and were grouped as positive PC1 values. Higher amounts of sugars were attributed to the majority of samples produced from older tubers, and they were distributed as negative PC1 values (Figure 2). Figure 3 shows a partial separation of the raw FCP samples from the cooked ones. According to the higher content of phenolics and sugars, the most of raw samples were placed as positive values of PC2. Cooked samples were distributed mostly as negative PC2 values, particularly the boiled FCP containing lower amounts of analyzed compounds.

FIGURE 1 Distribution of samples in the two-dimensional coordinate system defined by the first two principal components (PC1 and PC2) in relation to the cultivar

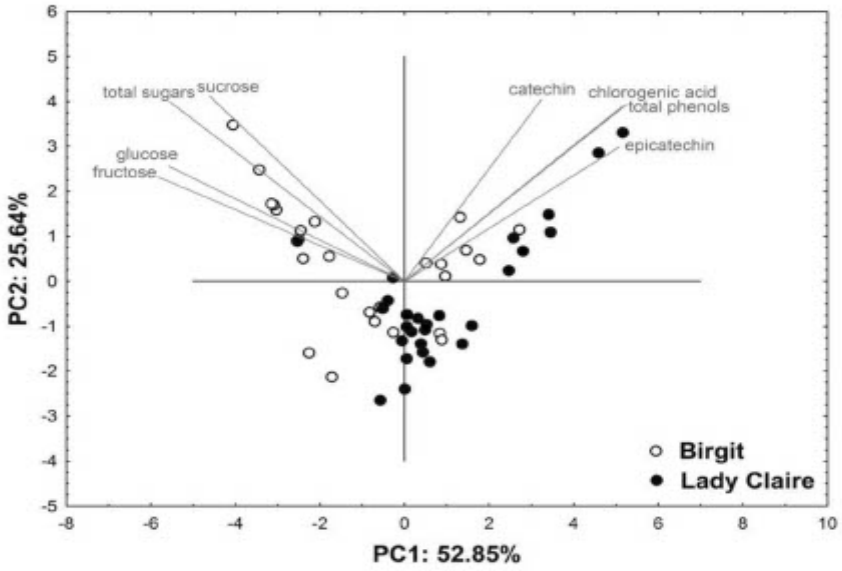
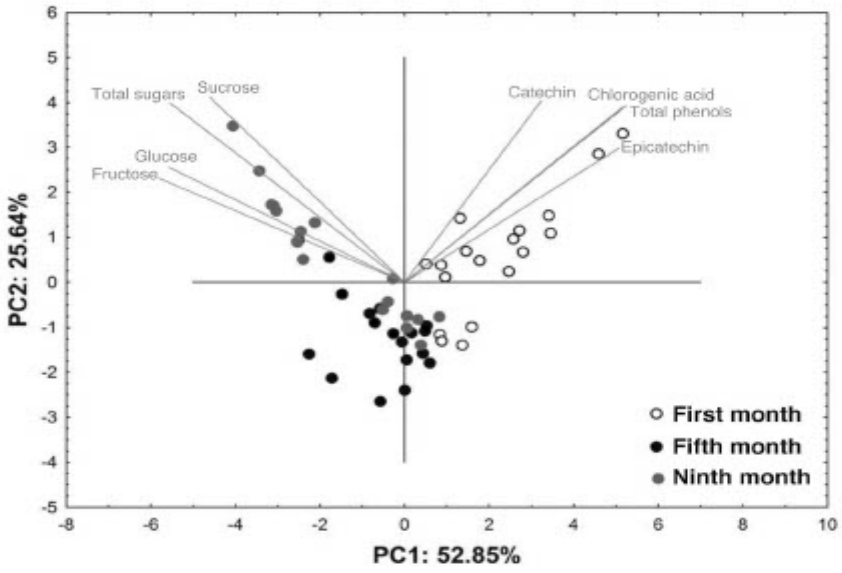


FIGURE 2 Distribution of samples in the two-dimensional coordinate system defined by the first two principal components (PC1 and PC2) in relation to the tubers' age



3.4 | Acrylamide analysis

The results of the influence of cultivar, tubers' age, and FCP storage on the AA in fried samples are given in Table 2. The average content of AA in all samples was 678.81 μg kg^{-1} DW and cultivar as well as FCP storage had a significant impact on the AA level. Much higher content of AA was found in the fried FCP of cv. Birgit (1025.87 μg kg^{-1} DW) when compared to cv. Lady Claire samples (331.75 μg kg^{-1} DW). This is probably due to the higher content of sugars found in cv. Birgit (Table 1), as sugars are stated as the main contributor to the higher amount of AA in fried potatoes (de Wilde et al., 2005; Elmore et al., 2015). Also, calculated Spearman's rank correlation coefficients in our study showed a strong correlation between AA and fructose ($r_s = 0.62$), glucose ($r_s = 0.79$), and sucrose ($r_s = 0.62$) as well as total sugars ($r_s = 0.76$). A significant correlation between glucose, fructose, or total reducing sugars from nine potato cultivars with AA formation was also previously reported (Halford et al., 2012). According to Biederman-Brem et al. (2003), reducing sugars' content below 1 g kg^{-1} FW is optimal to ensure AA under 500 μg kg^{-1} FW in fried and roasted potato. As shown in Table 1, the reducing sugars in cv. Birgit raw samples exceeded this level in contrast to cv. Lady Claire raw potatoes. Nevertheless, it should be pointed that AA content in cv. Birgit was under the

TABLE 2 The influence of cultivar, tubers' age, and cold storage on acrylamide content in fried fresh-cut potato

Source of variation	Acrylamide (μg kg^{-1} DW)
Cultivar	
	$p < 0.001$*
Birgit	1025.87 ± 88.29b
Lady Claire	331.75 ± 27.65a
Tubers' age (month)	
	$p = 0.634$
1	592.10 ± 110.41a
5	692.31 ± 135.20a
9	752.03 ± 145.05a
Storage (day)	
	$p = 0.030$*
0	448.58 ± 67.39a
5	610.85 ± 97.48ab
8	977.01 ± 159.15b
Cultivar × tubers' age (month)	
	$p < 0.001$*
Birgit × 1	906.89 ± 102.29b
Lady Claire × 1	277.31 ± 59.45a
	$p = 0.004$*
Birgit × 5	1048.26 ± 167.56b
Lady Claire × 5	336.35 ± 40.81a
	$p = 0.004$*
Birgit × 9	1122.47 ± 190.21b
Lady Claire × 9	381.60 ± 38.79a
Cultivar × storage (day)	
	$p = 0.004$*
Birgit × 0	668.48 ± 15.07b
Lady Claire × 0	228.69 ± 20.35a
	$p = 0.004$*
Birgit × 5	925.32 ± 33.51b
Lady Claire × 5	296.39 ± 33.60a
	$p = 0.004$*
Birgit × 8	1483.83 ± 93.03b
Lady Claire × 8	470.19 ± 6.88a
Storage (day) × tubers' age (month)	
	$p = 0.292$
0 × 1	415.76 ± 143.75a
5 × 1	524.75 ± 188.77a
8 × 1	835.81 ± 214.74a
	$p = 0.292$
0 × 5	451.68 ± 123.10a
5 × 5	619.17 ± 177.73a
8 × 5	1006.08 ± 316.88a

(Continues)

TABLE 2 (Continued)

Source of variation	Acrylamide (μg kg^{-1} DW)
	$p = 0.292$
0 × 9	478.32 ± 116.11a
5 × 9	688.64 ± 181.11a
8 × 9	1089.15 ± 347.81a
Grand mean	678.81

*Results are significant at $p < 0.05$.
Results are expressed as mean ± SE.
Values with different letters within the column are statistically different at $p < 0.05$.

referent value of 750 μg kg^{-1} FW for the AA level prescribed by the ECR 2017/2158 since the presented values are expressed on DW, which is about threefold higher when compared to FW. The level of AA in cv. Lady Claire was also below the ECR value, which is similar to previously reported results of Elmore et al. (2015). The amount of AA slightly increased with the age of tubers, although not significantly. This is in accordance with previously discussed results related to an increase of reducing sugars during tubers' aging. Similarly, Halford et al. (2012) reported that the level of AA in processed potatoes was positively correlated with the content of sugars in the potato tubers toward the end of long-term winter storage. Additionally, during the whole tubers' storage period cv. Birgit samples contained higher AA against samples of cv. Lady Claire (Table 2).

Considering all FCP samples, AA significantly increased with storage time, although the contents of reducing sugars, glucose, and fructose did not change significantly during that time. However, these reducing sugars' values present mean values of raw, boiled, and fried potatoes, therefore cannot be comparable. The data obtained for the cooking method versus FCP storage show that sugars in raw FCP also increased by the end of FCP storage, although not as much as AA in fried FCP. However, in fried FCP a decrease in phenolics was observed, and Kalita et al. (2013) and Zhu et al. (2010) declared that the level of AA was in a negative correlation with the content of total phenolics and chlorogenic acid. Additionally, as potato goes through textural changes during long-term storage (Dite Hunjek et al., 2020a) as well as during frying (Dourado et al., 2019; Miranda, & Aguilera, 2006), these textural changes could contribute to greater availability of reducing sugars for Maillard's reactions and consequently a higher level of AA despite similar amounts of reducing sugars.

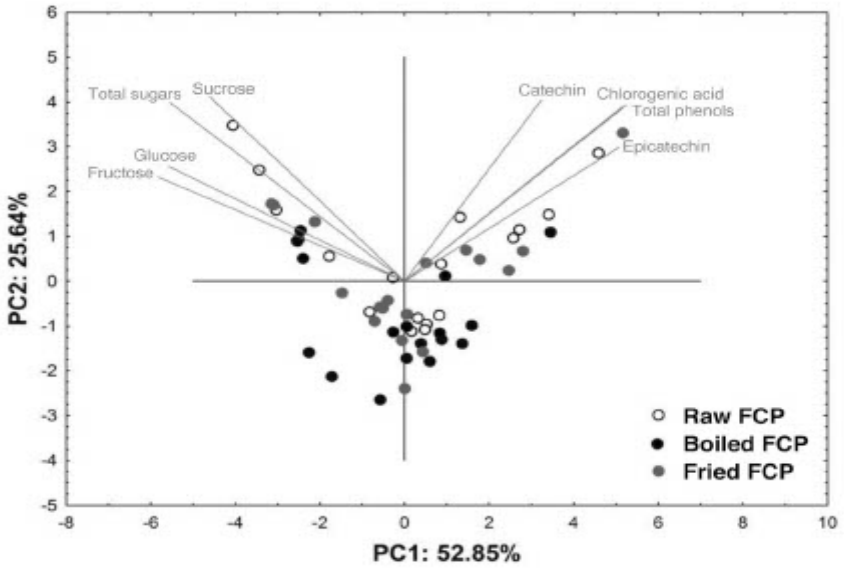


FIGURE 3 Distribution of samples in the two-dimensional coordinate system defined by the first two principal components (PC1 and PC2) in relation to the cooking method

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Chapter 5

Publication No. 4: Oil Uptake and Polycyclic Aromatic Hydrocarbons (PAH) in Fried Fresh-Cut Potato: Effect of Cultivar, Anti-Browning Treatment and Storage Conditions

Agronomy

Publication No. 4

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Maja Repajić -data curation, writing original draft
Tea Solarić-formal analysis
Draženka Dite Hunjek-formal analysis
Dubravka Škevin-review and editing original draft
Klara Kraljić-validation
Marko Obranović-formal analysis
Branka Levaj -conceptualization, project administration, supervision, review and editing original draft

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Article

Oil Uptake and Polycyclic Aromatic Hydrocarbons (PAH) in Fried Fresh-Cut Potato: Effect of Cultivar, Anti-Browning Treatment and Storage Conditions

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Abstract: This work examined the influence of cultivar, anti-browning treatment, package atmosphere and storage duration on the oil uptake and polycyclic aromatic hydrocarbons (PAH) levels in fried fresh-cut potato (FCP). Birgit and Lady Claire potato slices were pre-treated with sodium chloride solution (1%) and sodium ascorbate solution (2%), packaged in vacuum and modified atmosphere and stored at 10 °C/8 days. Oil uptake was significantly higher in Birgit FCP and was not affected by minimal processing. HPLC analysis/fluorescence detection was able to identify a total of 14 PAH. Benzo(a)pyrene and ΣPAH4 levels (0.62 and 1.36 μg kg^{-1}, respectively) were below the EU limits in all fried FCP samples. Majority of examined light and heavy PAH were higher in Lady Claire, while naphthalene, fluorene and pyrene were decreased by vacuum packaging. No differences in PAH levels were noted in FCP fried at the beginning and after 2, 4 and 8 days of storage.

Keywords: fresh-cut potato; Birgit; Lady Claire; frying; oil uptake; PAH; benzo(a)pyrene

1. Introduction

Market segment of busy consumers, which demand convenient and easy-to-use food products, is evermore increasing [1]. On the other hand, there is a growing perception of industrially processed foods and ready meals being less "natural" and "unhealthy" [2]. This large gap is recently being addressed by the food industry through the production of minimally processed or fresh-cut (FC) food products. Besides convenience, FC products also offer preserved nutritive value and prolonged freshness [3,4].

With 2017 global production of around 390 million tonnes and cultivation area of almost 8 million ha, potato (*Solanum tuberosum* L.) is still the most widely consumed vegetable and one of the world's largest food crops, third only to rice and wheat [5]. As the consumer demand for FCP is steadily increasing and new products are being launched on the market, there is also a growing scientific interest for the appropriate potato cultivars and treatments that will enable prolonged shelf-life of such products [6]. Therefore, various anti-browning treatments and storage conditions used to prevent the appearance of negative colour changes and to maximally extend the shelf-life have been investigated [7–12]. Furthermore, physiological aging of FC product due to respiration could be delayed with storage under decreased oxygen level, e.g., vacuum (VP) or modified atmosphere packaging (MAP) [9]. Similar results were obtained in our previous study [13] where VP and MAP in comparison with packaging in the passive atmosphere (more abundant with oxygen) on durability of FCP were examined.

In addition, as most potatoes are consumed fried in the form of French fries or chips [14], it is important to determine the influence of FC processing and storage conditions on the nutritional value and safety of such products. Since these innovative processing, packaging and preparation methods place these products in the novel food group as determined by EFSA through the EU Regulation 2015/2283, thorough risk assessment is necessary in order to enable their safe consumption [15]. One of the major health risks connected with the consumption of fried foods in general is its oil uptake. The amount of absorbed oil is increased by the higher surface/volume ratio, lower dry matter content and lower frying temperatures [16–18].

In addition, food processed by frying in general, as well as French fries and potato chips are often related to elevated levels of heat-induced toxic chemicals such as acrylamide, furans and PAH [19]. PAH represent a large group of ubiquitous contaminants composed of 2 or more aromatic rings and are formed by incomplete burning of organic matter. Their toxicity increases by the number of rings according to which they can be classified as light fraction (2–4 rings) and heavy fraction (containing more than 4 rings). PAH contamination of food occurs by the means of environmental pollution as well as heat processing [20]. Genotoxic and mutagenic activity of PAH is often attributed to the heavy fraction, while their light fraction can cause systemic toxic effects [21]. PAH in fried food can originate from raw food, frying oil and frying itself, however, considering that refined vegetable oil is used for frying and replaced on regular basis, PAH appearance can be linked to cultivar properties, growth conditions and post-harvest processing [22–25]. EU Regulation 835/2011 amending Regulation 1881/2006 set new limits for the concentration of PAH in food [26]. Maximum limit of 2 μg kg^{-1} in oils for human consumption or used as ingredients for benzo(a)pyrene was complemented by the sum of so called PAH4 (benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene and chrysene) set to 10 μg kg^{-1}.

Based on the background described above, this study aimed to access the influence of the cultivar, anti-browning treatment as well as packaging atmosphere and storage duration on the oil uptake and the content of PAH contaminants in fried FCP slices.

2. Materials and Methods

2.1. Materials

Applied experimental setup and FCP preparation procedure derived from the results of previous studies through which the most satisfactory packaging (films for VP and MAP) as well as storage conditions (temperature) and duration (up to 8 days) were selected based on microbiological and sensory assays [13]. Briefly, potatoes (*Solanum tuberosum* cv. Birgit and Lady Claire) grown in Croatia (Slavonia, 45°40′ N, 17°1′ E) were used for the experiment. After harvesting, tubers were stored in the dark at 8 °C/100% RH and 3 days before processing at 16 °C. Uniform and undamaged tubers with diameter greater than 35 mm were hand-peeled, tap water washed and cut into 5 mm thick slices using commercial cutting machine (MCM62020-CNCM30, Multitalent, Robert Bosch d.o.o., Škofja Loka, Slovenia). Immediately after cutting, slices were inspected for absence of visual defects and immersed for 3 min in sodium chloride (1%, *w*/*v*) (Solana d.d., Tuzla, Bosnia and Herzegovina) or sodium ascorbate (2%, *w*/*v*) (Nutrimedica d.o.o., Zagreb, Croatia) with sample/solution ratio of 1:4 (*w*/*v*). Slices were then strained using stainless steel colander to reduce the water content and packaged (300 g) using two different packaging methods: VP and MAP (10.0% CO_2, 3.0% O_2, 87.0% N_2). For VP samples polyamide/polyethylene (PA/PE) bags with film thickness 90 μm (permeability at 23 °C and RH 0% for O_2 was 8.21 cm^3 m^{-2} day^{-1} bar^{-1}) were used and MAP was carried out in PA/PE bags with film thickness 75 μm (permeability for O_2 was 22.3 cm^3 m^{-2} day^{-1} bar^{-1}) [27]. The samples undergoing VP were sealed by exclusion of air from the bags using vacuum sealer (WS110W vacuum packager, Gorenje, Velenje, Slovenia), while MAP was achieved by gas mixture injection with Junior Digit device (Besser Vacuum, Dignano, Italy). All samples were stored at 10 °C/8 days. For analytical purposes, initially and after 2, 4 and 8 days, 180 g of raw slices were fried in 1.5 L of refined sunflower

oil at 180 °C/5 min using commercial fryer (FR490070, Tefal, Rumilly, France). After frying, excess oil was absorbed by paper towels, fried slices were cooled at ambient temperature and stored at −20 °C until further analysis. For analysis purpose, dry matter of the raw potatoes was determined by drying at 103 ± 2 °C to constant mass [28].

2.2. Oil Extraction

Representative sample (50 g) of fried potato slices, for each factor combination, were mashed into puree using pestle and mortar. Prepared purees (10 g) were placed in Erlenmeyer flask and extracted with 30 mL of hexane in ultrasonic bath (RK 100 H, Bandelin electronic GmbH & Co., Berlin, Germany) for 60 min. Obtained suspension was filtered through Whatman filter paper which was afterwards rinsed by 3 portions of hexane (10 mL each) and solvent was removed on a rotary evaporator at 40 °C and 300 mbar [29]. Extracted lipid fraction was stripped of the remaining solvent under the flow of nitrogen and afterwards weighed. Determined weight was used to assess the oil uptake during frying. Extracted lipids were then dissolved to 1 mL with cyclohexane and used for HPLC determination of PAH.

2.3. PAH Isolation and Determination

PAH isolation was performed by donor-acceptor complex chromatography (DACC) that was previously developed by Nederal et al. (2013) [30]. HPLC pump (Pharmacia LKB Biotechnology AB, Uppsala, Sweden) with 250 µL injector loop was employed to load the sample to the Varian Chromspher Pi 80 × 3 mm column (Sint-Katelijn-Waver, Belgium). Triacylglycerols were stripped by the elution with iso-propanol at 0.35 mL min^{-1} during 11.5 min. PAH remaining on the isolation column were afterwards back-flushed by secondary HPLC pump (Varian 9010, Varian, Sint-Katelijn-Waver, Belgium) onto the two inter-connected analytical Pursuit 5 PAH 250 × 4.6 mm × 5 µm (Varian, Sint-Katelijn-Waver, Belgium) columns which were heated to 30 °C. After each elution, DACC column was cleaned by iso-propanol at 0.35 mL min^{-1} for 10 min. Water, ethyl-acetate and acetonitrile were used with gradient program shown in Table 1.

Table 1. Gradient program for the separation of PAH.

Time (min)	Flow (mL min^{-1})	%A (Water)	%B (Ethyl-Acetate)	%C (Acetonitrile)
0	0.4	20	0	80
2.49	0.4	20	0	80
2.50	1	20	0	80
3.90	1	20	0	80
17.90	1	0	0	100
45.99	1	0	0	100
46.00	1	0	30	70
68.00	1	0	30	70
69.00	1	0	0	100
73.00	1	0	0	100
83.00	1	20	0	80
90.00	0.40	20	0	80

Varian Pro Star 363 fluorescence detector (Varian, Sint-Katelijn-Waver, Belgium) running a detection program (Table 2) was used to assess the eluted PAH. Besides oils extracted from fried potato slices, PAH content was also determined in fresh sunflower oil used for frying.

Table 2. Fluorescence detector program for detection of individual PAH compounds.

Time (min)	Excitation (nm)	Emission (nm)	PAH Detected
0.0	225	320	-
14.5	256	390	Fluorene, phenanthrene, anthracene
16.7	240	460	Fluoranthene
18.0	240	390	Pyrene
19.5	270	385	Benzo(a)anthracene, chrysene
24.0	290	430	Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene
39.0	305	480	Benzo(g,h,i)perylene, indeno(1,2,3,-c,d)pyrene
55.0	305	480	-

2.4. PAH Quantification and Validation

Calibration and validation were done by spiking of blank oil matrix with 16 EPA PAH standards dissolved in methylene chloride:methanol (1:1) (Supelco, Bellefonte, PA, USA). Phenanthrene, anthracene, pyrene, benzo(a)anthracene, chrysene, benzo(k)fluoranthene and benzo(a)pyrene were calibrated at 0.25–17.5 μg kg^{-1} of lipid fraction, while the calibration ranges used for fluorene, fluoranthene, benzo(b)fluoranthene, benzo(a,h)anthracene and benzo(g,h,i)perylene were 0.5–35 μg kg^{-1}. Because of its lower fluorescence, indeno(1,2,3-c,d)pyrene was calibrated in the range of 1–60 μg kg^{-1}. Linearity was established for all analysed standards with correlation coefficients above 0.999 in the studied range. Limit of detection (LOD) and limit of quantification (LOQ) were determined by the injection of seven blanks spiked with PAH at the lowest level of calibration for each PAH analysed and calculated from the slope of calibration curve (S) and standard deviation of the response (σ) as LOD = 3.3 σ/S and LOQ = 10 σ/S, respectively. LOD and LOQ ranged from 0.04–0.61 μg kg^{-1} and 0.13–1.84 μg kg^{-1}, therefore showing satisfactory sensitivity of the method. Recoveries were 94.1–109.4%, while the repeatability testing showed relative standard deviations 2.7–4.3%, which is considered sufficient based on ICH procedures for validation of analytical methods [31]. All measurements were done with at least two determinations.

2.5. Statistical Analysis

For the statistical analysis, full factorial randomized experimental design was employed, where independent categorical variables were: (a) cultivar type (cv. Birgit and Lady Claire), (b) anti-browning agent [sodium chloride (1%), sodium ascorbate (2%)], (c) package atmosphere (VP, MAP) and (d) storage time (0, 2, 4 and 8 days), while oil uptake and determined PAH compounds were dependent continuous variables. Total number of 32 samples (sub-sets of 16 samples for each cultivar, anti-browning agent, package atmosphere and 8 samples for each day) were included in the study and multifactorial analysis of variance followed by post-hoc Tukey's test as well as Principal Component Analysis (PCA) was performed by XLSTAT software at the $p \leq 0.05$ significance level. Statistical analysis was done with replicates included and its results are shown as least square mean ± standard error (SE).

3. Results and Discussion

3.1. Oil Uptake

Considering that water is replaced by oil during frying, potato cultivars with higher dry matter content were shown to absorb less oil [32]. Ziaiifar (2008) [33] found that oil intake of fried potatoes is also affected by pre-treatments such as blanching, air drying, osmotic dehydration, steam frying, and coating application such as starch, gelatine, protein, carboxymethyl cellulose, etc. In addition,

oil uptake is dependent on the thickness and shape of fried potatoes as potato chips can contain up to 40% of oil, while French fries contain less than 15%.

In this work, weight of oil extracted from fried potato slices during PAH analysis were expressed as a percentage of fried potato weight and used to assess the influence of cultivar, anti-browning pre-treatment and storage conditions on the oil uptake (Figure 1).

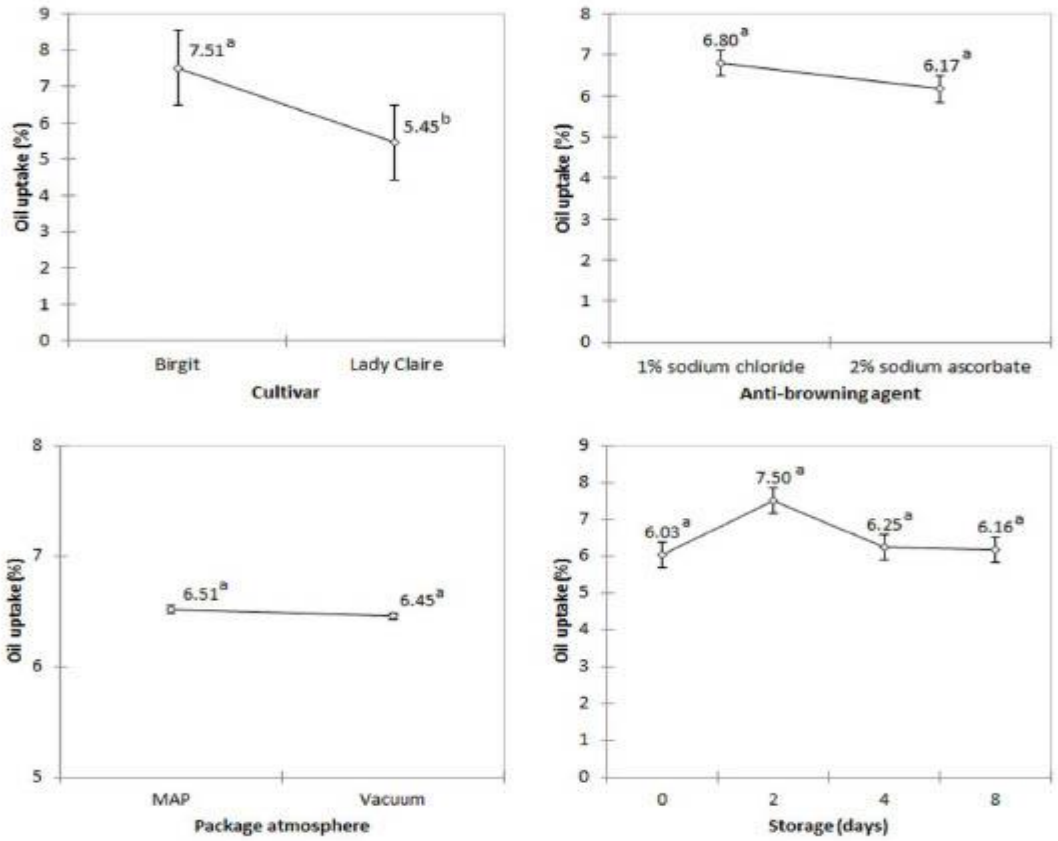

Figure 1. Oil uptake in fried fresh-cut potato as affected by cultivar, anti-browning agent, packaging and storage duration. Results are expressed as mean ± SE of $n = 16$ for cultivars, anti-browning agents, package atmospheres and $n = 8$ for days. Values with different letters are statistically different at $p \leq 0.05$.

Oil content was somewhat lower than previously determined by Ziaiifar (2008) [33] and it ranged from 5.34–11.22% of total weight with an average of 6.48%. Potato slices analysed in this work were 5 mm thick and their area/volume ratio was lower than in standard industrial chips, which can explain lower oil uptakes. Oil uptake was significantly influenced only by cultivar ($p < 0.01$), while anti-browning pre-treatment with sodium chloride and sodium ascorbate as well as packaging conditions (VP and MAP) and storage time did not cause significant differences. Fried potato slices produced from cv. Birgit had higher oil content than those from cv. Lady Claire (7.51 and 5.45%, respectively). Considering that the dry matter content between cv. Birgit and Lady Claire were significantly different at $p < 0.01$ (18.45% and 24.21%, respectively), these results were well expected. Elfnesh et al. (2011) [34] recommend that cultivars with more than 19.5% of dry matter should be used

to produce French fries, while potato chips should be prepared from cultivars with dry matter content higher than 20%.

In addition, the results deriving from this work are in line with those obtained by other authors that investigated the influence of FC processing on oil uptake in fried potatoes. Oner and Walker (2010) [35] blanched potato strips at 60 °C in 0.5% $CaCl_2$ solution for 20 min, cooled to 20 °C and re-blanched with water at 98 °C for 5 min. The potato strips prepared in this way were treated with ozone gas, sodium metabisulphite solution, etc., packaged under near-aseptic conditions or in vacuum and stored at 7 ± 1 °C for 28 days. Results for FCP when compared to frozen commercial fries showed significantly lower oil uptake after frying, i.e., 7.9–8.2% and 21.6%, respectively. No significant differences were however observed between the content of absorbed oil and the way the FCP were treated.

On the other hand, Krokida et al. (2001) [36] showed that immersing or spraying raw potatoes with 40% sucrose and 20% sodium chloride solution, when applied as a pre-treatment for frying, caused an osmosis dehydration and consequently had a significant effect on the oil absorption. The potatoes treated with sucrose solution had 60% less oil and the ones treated with sodium chloride solution 35% less oil than control. Such treatment caused browning after frying and was more pronounced when sucrose solution was applied. Even though their work points out to osmotic dehydration as an effective method of lowering the oil uptake in the fries, conditions used in this study, i.e., 3 min of immersion and low salt concentrations resulted in similar oil uptakes without disrupting the colour of fried slices.

3.2. PAH Determination

Used fluorescence detection was able to identify a total of 14 PAH. Compared to the recommendations of EFSA (2007) [37] that call for 16 PAH monitoring, acenaphthylene, which is not fluorescent, could not be identified due to the limitations of fluorescence detector. Acenaphthylene and indeno(1,2,3-c,d)perylene were below the methods detection limit in all samples. Out of all detected light PAH compounds, naphthalene was dominant (0.46–8.52 μg kg^{-1}) and followed by phenanthrene (ND–5.44 μg kg^{-1}), fluoranthene (ND–3.31 μg kg^{-1}) and acenaphthene (0.07–3.11 μg kg^{-1}) with grand mean values being 3.52, 1.58, 0.97 and 0.85 μg kg^{-1}, respectively (Table 3). These results correspond well to the light fraction range established for the oils extracted from fried potato samples in the work of Purcaro et al. (2006) [29]. In their research naphthalene was also the main PAH compound, followed by phenanthrene, fluoranthene and pyrene.

On the other hand, heavy PAH fraction (Table 4) was dominated by benzo(g,h,i)perylene, benzo(b)fluoranthene, dibenzo(a,h)anthracene and benzo(a)pyrene with respective mean values of 0.38, 0.14, 0.14 and 0.13 μg kg^{-1}. In addition, maximum determined level of benzo(a)pyrene was 0.62 μg kg^{-1}, which is below the limit of 2 μg kg^{-1} set by the EU Regulation 835/2011 [26].

In 2008 the EFSA Panel on Contaminants in the Food Chain (CONTAM) concluded that benzo(a)pyrene alone is not a suitable marker for measuring PAH content in food and proposed that a total of benzo(a)pyrene, chrysene, benzo(b)fluoranthene and benzo(a)anthracene, so called PAH4 group, should be used as additional PAH contamination indicator [38]. Based on this recommendation, EU Regulation 835/2011 [26] therefore set a limit of 10 μg kg^{-1} for the PAH4 group in oils intended for direct consumption or used as a food ingredient. PAH4 content of oils extracted from all analysed fried potato samples was lower than the set limit and varied from 0.28–1.36 μg kg^{-1}. Similarly, Purcaro et al. (2006) [29] also found heavy PAH levels in oils extracted from industrial snacks below the EU limits. Furthermore, Kumosani et al. (2013) [39] assessed the contents of pyrene, benzo(a)anthracene, benzo(e)pyrene, benzofluoranthene and benzo(a)pyrene, in conventionally and microwave fried potato samples, and could not detect any of the examined compounds.

Table 3. Light (2–4 rings) PAH fraction (μg kg^{-1}) in fried fresh-cut potato as affected by cultivar, anti-browning agent, packaging and storage duration.

Source of Variation	Naphthalene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Benzo(a)-Anthracene	Chrysene	Pyrene
Cultivar	$p < 0.01$ *	$p < 0.01$ *	$p < 0.01$ *	$p < 0.01$ *	$p = 0.58$	$p = 0.34$	$p < 0.01$ *	$p < 0.01$ *	$p < 0.01$ *
Birgit	2.02 ± 0.36 ^{b}	1.48 ± 0.12 ^{a}	0.01 ± 0.05 ^{b}	0.38 ± 0.27 ^{b}	0.32 ± 0.13 ^{a}	1.10 ± 0.19 ^{a}	0.17 ± 0.02 ^{b}	0.07 ± 0.02 ^{b}	0.02 ± 0.04 ^{b}
Lady Claire	5.03 ± 0.36 ^{a}	0.22 ± 0.12 ^{b}	0.87 ± 0.05 ^{a}	2.79 ± 0.27 ^{a}	0.43 ± 0.13 ^{a}	0.84 ± 0.19 ^{a}	0.40 ± 0.02 ^{a}	0.29 ± 0.02 ^{a}	0.74 ± 0.04 ^{a}
Anti-browning agent	$p = 0.34$	$p = 0.38$	$p = 0.09$	$p = 0.87$	$p = 0.37$	$p = 0.38$	$p = 0.19$	$p = 0.99$	$p = 0.73$
1% sodium chloride	3.78 ± 0.36 ^{a}	0.93 ± 0.12 ^{a}	0.38 ± 0.05 ^{a}	1.62 ± 0.27 ^{a}	0.46 ± 0.13 ^{a}	0.85 ± 0.19 ^{a}	0.26 ± 0.02 ^{a}	0.18 ± 0.02 ^{a}	0.39 ± 0.04 ^{a}
2% sodium ascorbate	3.26 ± 0.36 ^{a}	0.77 ± 0.12 ^{a}	0.50 ± 0.05 ^{a}	1.55 ± 0.27 ^{a}	0.29 ± 0.13 ^{a}	1.09 ± 0.19 ^{a}	0.31 ± 0.02 ^{a}	0.18 ± 0.02 ^{a}	0.37 ± 0.04 ^{a}
Package atmosphere	$p = 0.04$ *	$p = 0.66$	$p = 0.03$ *	$p = 0.25$	$p = 0.34$	$p = 0.79$	$p = 0.07$	$p = 0.09$	$p = 0.02$ *
Vacuum	2.92 ± 0.36 ^{b}	0.81 ± 0.12 ^{a}	0.36 ± 0.05 ^{b}	1.35 ± 0.27 ^{a}	0.28 ± 0.13 ^{a}	1.01 ± 0.19 ^{a}	0.25 ± 0.02 ^{a}	0.15 ± 0.02 ^{a}	0.30 ± 0.04 ^{b}
Modified	4.12 ± 0.36 ^{a}	0.89 ± 0.12 ^{a}	0.52 ± 0.05 ^{a}	1.82 ± 0.27 ^{a}	0.47 ± 0.13 ^{a}	0.94 ± 0.19 ^{a}	0.32 ± 0.02 ^{a}	0.21 ± 0.02 ^{a}	0.46 ± 0.04 ^{a}
Storage (days)	$p = 0.47$	$p = 0.23$	$p = 0.16$	$p = 0.63$	$p = 0.23$	$p = 0.32$	$p = 0.08$	$p = 0.73$	$p = 0.81$
0	3.10 ± 0.51 ^{a}	0.70 ± 0.17 ^{a}	0.58 ± 0.07 ^{a}	1.81 ± 0.38 ^{a}	0.25 ± 0.19 ^{a}	0.55 ± 0.26 ^{a}	0.31 ± 0.03 ^{a}	0.17 ± 0.03 ^{a}	0.42 ± 0.06 ^{a}
2	4.20 ± 0.51 ^{a}	1.18 ± 0.17 ^{a}	0.39 ± 0.07 ^{a}	1.33 ± 0.38 ^{a}	0.30 ± 0.19 ^{a}	1.26 ± 0.26 ^{a}	0.34 ± 0.03 ^{a}	0.21 ± 0.03 ^{a}	0.37 ± 0.06 ^{a}
4	3.24 ± 0.51 ^{a}	0.80 ± 0.17 ^{a}	0.41 ± 0.07 ^{a}	1.33 ± 0.38 ^{a}	0.21 ± 0.19 ^{a}	1.04 ± 0.26 ^{a}	0.23 ± 0.03 ^{a}	0.18 ± 0.03 ^{a}	0.35 ± 0.06 ^{a}
8	3.55 ± 0.51 ^{a}	0.72 ± 0.17 ^{a}	0.39 ± 0.07 ^{a}	1.87 ± 0.38 ^{a}	0.73 ± 0.19 ^{a}	1.03 ± 0.26 ^{a}	0.25 ± 0.03 ^{a}	0.16 ± 0.03 ^{a}	0.38 ± 0.06 ^{a}
Cultivar x Package atmosphere	$p = 0.01$ *	$p = 0.41$	$p = 0.03$ *	$p = 0.01$ *	$p = 0.23$	$p = 0.06$	$p = 0.14$	$p = 0.14$	$p < 0.01$ *
Birgit × Vacuum	2.26 ± 0.51 ^{b}	1.51 ± 0.17 ^{a}	0.01 ± 0.07 ^{c}	0.75 ± 0.38 ^{bc}	0.34 ± 0.19 ^{a}	1.41 ± 0.26 ^{a}	0.16 ± 0.03 ^{b}	0.06 ± 0.03 ^{b}	0.05 ± 0.06 ^{c}
Birgit × Modified	1.78 ± 0.51 ^{b}	1.44 ± 0.17 ^{a}	0.01 ± 0.07 ^{c}	0.01 ± 0.38 ^{c}	0.30 ± 0.19 ^{a}	0.79 ± 0.26 ^{a}	0.18 ± 0.03 ^{b}	0.07 ± 0.03 ^{b}	0.00 ± 0.06 ^{c}
Lady Claire × Vacuum	3.58 ± 0.51 ^{b}	0.11 ± 0.17 ^{b}	0.71 ± 0.07 ^{b}	1.96 ± 0.38 ^{bc}	0.21 ± 0.19 ^{a}	0.60 ± 0.26 ^{a}	0.34 ± 0.03 ^{a}	0.24 ± 0.03 ^{a}	0.56 ± 0.06 ^{b}
Lady Claire × Modified	6.47 ± 0.51 ^{a}	0.34 ± 0.17 ^{b}	1.03 ± 0.07 ^{a}	3.62 ± 0.38 ^{a}	0.64 ± 0.19 ^{a}	1.08 ± 0.26 ^{a}	0.45 ± 0.03 ^{a}	0.35 ± 0.03 ^{a}	0.91 ± 0.06 ^{a}
Grand mean (n = 32)	3.52	0.85	0.44	1.58	0.37	0.97	0.28	0.18	0.38

* Statistically significant variable at $p \leq 0.05$. Results are expressed as mean ± SE of n = 16 for cultivars, anti-browning agents, package atmospheres and n = 8 for days and cultivars × package atmospheres. Values in the same column with different letters are statistically different at $p \leq 0.05$.

Table 4. Heavy (5 and 6 rings) PAH fraction (μg kg^{-1}) in fried fresh-cut potato as affected by cultivar, anti-browning agent, packaging and storage duration.

Source of Variation	Benzo(b)-Fluoranthene	Benzo(k)-Fluoranthene	Benzo(a)-Pyrene	Dibenzo(a,h)-Anthracene	Benzo(g,h,i)-Perylene
Cultivar	$p < 0.01$ *	$p = 0.14$	$p = 0.02$ *	$p = 0.97$	$p < 0.01$ *
Birgit	0.06 ± 0.02 ^{b}	0.05 ± 0.01 ^{a}	0.08 ± 0.03 ^{b}	0.14 ± 0.05 ^{a}	0.19 ± 0.06 ^{b}
Lady Claire	0.22 ± 0.02 ^{a}	0.08 ± 0.01 ^{a}	0.18 ± 0.03 ^{a}	0.14 ± 0.05 ^{a}	0.57 ± 0.06 ^{a}
Anti-browning agent	$p = 0.23$	$p = 0.17$	$p = 0.79$	$p = 0.95$	$p = 0.12$
1% sodium chloride	0.12 ± 0.02 ^{a}	0.06 ± 0.01 ^{a}	0.12 ± 0.03 ^{a}	0.14 ± 0.05 ^{a}	0.31 ± 0.06 ^{a}
2% sodium ascorbate	0.15 ± 0.02 ^{a}	0.08 ± 0.01 ^{a}	0.13 ± 0.03 ^{a}	0.14 ± 0.05 ^{a}	0.45 ± 0.06 ^{a}
Package atmosphere	$p = 0.05$ *	$p = 0.66$	$p = 0.19$	$p = 0.76$	$p = 0.14$
Vacuum	0.11 ± 0.02 ^{b}	0.07 ± 0.01 ^{a}	0.15 ± 0.03 ^{a}	0.13 ± 0.05 ^{a}	0.45 ± 0.06 ^{a}
Modified	0.17 ± 0.02 ^{a}	0.06 ± 0.01 ^{a}	0.10 ± 0.03 ^{a}	0.15 ± 0.05 ^{a}	0.32 ± 0.06 ^{a}
Storage (days)	$p = 0.95$	$p = 0.67$	$p = 0.07$	$p = 0.49$	$p = 0.18$
0	0.13 ± 0.03 ^{a}	0.07 ± 0.02 ^{a}	0.10 ± 0.04 ^{a}	0.13 ± 0.07 ^{a}	0.46 ± 0.08 ^{a}
2	0.15 ± 0.03 ^{a}	0.08 ± 0.02 ^{a}	0.22 ± 0.04 ^{a}	0.19 ± 0.07 ^{a}	0.50 ± 0.08 ^{a}
4	0.13 ± 0.03 ^{a}	0.05 ± 0.02 ^{a}	0.11 ± 0.04 ^{a}	0.19 ± 0.07 ^{a}	0.29 ± 0.08 ^{a}
8	0.14 ± 0.03 ^{a}	0.07 ± 0.02 ^{a}	0.08 ± 0.04 ^{a}	0.06 ± 0.07 ^{a}	0.27 ± 0.08 ^{a}
Cultivar x Package atmosphere	$p = 0.32$	$p = 0.14$	$p = 0.02$ *	$p = 0.81$	$p = 0.21$
Birgit × Vacuum	0.04 ± 0.03 ^{b}	0.07 ± 0.02 ^{a}	0.15 ± 0.04 ^{ab}	0.16 ± 0.07 ^{a}	0.69 ± 0.08 ^{ab}
Birgit × Modified	0.07 ± 0.03 ^{b}	0.04 ± 0.02 ^{a}	0.00 ± 0.04 ^{b}	0.15 ± 0.07 ^{a}	0.45 ± 0.08 ^{ab}
Lady Claire × Vacuum	0.18 ± 0.03 ^{a}	0.07 ± 0.02 ^{a}	0.15 ± 0.04 ^{ab}	0.12 ± 0.07 ^{a}	0.20 ± 0.08 ^{b}
Lady Claire × Modified	0.26 ± 0.03 ^{a}	0.09 ± 0.02 ^{a}	0.20 ± 0.04 ^{a}	0.14 ± 0.07 ^{a}	0.18 ± 0.08 ^{b}
Grand mean (n = 32)	0.14	0.07	0.13	0.14	0.38

* Statistically significant variable at $p \leq 0.05$. Results are expressed as mean ± SE of $n = 16$ for cultivars, anti-browning agents, package atmospheres and $n = 8$ for days and cultivars × package atmospheres. Values in the same column with different letters are statistically different at $p \leq 0.05$.

As PAH contamination of food products can be related to the environmental and processing conditions, PAH in fried potatoes can originate from the frying oil and frying process but also from the potatoes themselves. In general, oilseeds contain high amounts of triacylglicerols and are, therefore, prone to uptake of lipophilic molecules such as PAH from soils [40,41]. During oil production these PAH, together with the ones that contaminate seeds during post-harvest are extracted to crude oil, however, they are removed by refining [42–44]. Therefore, frying oils are usually not likely to be the main sources of PAH contamination in fried food. PAH analysis performed on the fresh, refined sunflower oil used in this work could not identify any of the examined compounds.

In addition, as several authors concluded that the usual temperatures applied during typical domestic frying, such as 180 °C that was used in this work, do not induce PAH formation, frying oil and process are not likely to be a source of contamination [29,45].

Hence, since no PAH contamination was detected in the utilized sunflower oil, and frying temperature as well as duration was too short to enable PAH formation, PAH origin was probably environmental, i.e., related to soil contamination of potatoes. According to Bansal and Kim (2015) [46], compared to other vegetable species, root vegetables such as potatoes uptake more PAH from the contaminated soils. Results on PAH content in fresh potatoes vary significantly between studies of different authors. Ashraf et al. (2012) [47] studied PAH contents in fresh vegetables originating from Saudi Arabia and found the highest levels present in analysed potato samples (11 μg kg^{-1}). In general, vegetable skin was more contaminated than the flesh, and contamination was in proportion to the degree of environmental pollution. They concluded that due to the high consumption of potatoes, these levels could represent a significant PAH exposure source. Similar results for vegetables grown in Denmark were found by Samsøe-Petersen et al. (2002) [23]. Wennrich et al. (2002) [24] also found higher total PAH levels (μg kg^{-1}) in potatoes when compared to other vegetables, while Zhong and Wang (2002) [25] observed PAH levels in potatoes up to 12.54 μg kg^{-1}. In their research Abou-Arab et al. (2014) [22] found approximately 6.2 μg kg^{-1} of total PAH and 2.4 μg kg^{-1} of PAH4. Regardless of the significant PAH levels in fresh potatoes, Purcaro et al. (2006) [29] consider that environmental contamination of potato with PAH does not attribute to its final concentrations in fries because potatoes are being washed and peeled before frying. However, Kulhánek et al. (2005) [48], which assessed the

human exposure to PAH from vegetable origin, showed that root vegetables represent a dominant diet source of vegetable PAH, even after careful peeling is assumed. Nevertheless, besides adding to the possibility that PAH contamination in fried potatoes is related to the environmental contamination, reported differences in PAH concentrations obtained by various authors indicate that they are affected by the growth conditions, region or cultivar.

3.3. Effect of Cultivar

Different authors have shown that some cultivars can be more suitable for FC as they differ in phenolics, ascorbic acid, soluble sugars and polyphenol oxidase activity that affect enzymatic browning [8,49,50]. However, during the selection of the most appropriate cultivar, safety of FCP such as acrylamide formation potential [51] and PAH content should also be taken into consideration.

In previous research of Dite Hunjek et al. (2020) [13] cv. Birgit and Lady Claire showed a good potential for FC processing. According to the European Cultivated Potato Database [52], cv. Birgit is a novel German cultivar of table potatoes and it is not inclined to browning, while cv. Lady Claire is a common industrial cultivar mostly used in chips industry [53]. However, to our best of knowledge, there are no literature data on PAH contents in these two cultivars.

Results obtained in this work showed a significant influence of potato cultivar on the PAH contents in oils extracted from fried FCP. Light PAH fraction species data presented in Table 3 reveal significant differences in the contents of naphthalene, acenaphthene, fluorene, phenanthrene, benzo(a)anthracene, chrysene and pyrene determined in Birgit and Lady Claire potato cultivars. Overall, light PAH contents were higher ($p < 0.01$) in cv. Lady Claire samples. Furthermore, Lady Claire also contained higher levels of heavy PAH (Table 4), i.e., benzo(b)fluoranthene ($p < 0.01$), benzo(a)pyrene ($p = 0.02$) and benzo(g,h,i)perylene ($p < 0.01$), which values were 2.5–3.5 fold higher than those measured for cv. Birgit (0.06–0.22 μg kg^{-1}, 0.08–0.18 μg kg^{-1} and 0.19–0.57 μg kg^{-1}, respectively). Similarly, PAH4 levels (Figure 2) were higher in cv. Lady Claire FCP (1.09 μg kg^{-1}) compared to cv. Birgit (0.38 μg kg^{-1}).

Total PAH content (Figure 3) was also significantly influenced by cultivar, with levels being twofold higher in cv. Lady Claire samples (12.53 vs. 6.56 μg kg^{-1}).

Although there are no previously published results on comparison of PAH contents in different potato varieties, the effect of cultivar on the PAH intake and accumulation have been noticed for other crops, e.g., coffee and rice [54,55]. Differences in PAH uptake between various plants and plant parts have also been studied by Fismes et al. (2002) [56]. They found higher levels of PAH in whole tubers when compared to the peeled potatoes, which they explain by higher lipid contents in peels. In addition, PAH levels were also higher in carrots that have high lipid content and, consequently, greater potential to accumulate non-polar molecules. Even though original PAH content in fried FCP might have been somewhat diluted due to the higher oil uptake, greater PAH contamination found in cv. Lady Claire samples can therefore be explained by the higher lipid content of cv. Lady Claire tubers which was determined at 0.77% compared to 0.58% in cv. Birgit.

To further examine and visualise the interrelationship of determined differences in PAH species between cultivars included in this study, PCA was implemented (Figure 4). Based on the preliminary PCA, a total of 13 active variables with a communality value ≥0.5 were selected. PCA run included 32 observations and identified two main factors with eigenvalues of 8.488 and 1.561, respectively, which accounted for 77.30% of total data variance. First factor (F1) represented 65.29% of total variance and very strongly positively correlated with the majority of light fraction PAH species and all components from the heavy fraction as well as with sums of total PAH and PAH4. Acenaphthene was the only light PAH that had a positive correlation with the second factor (F2) which was also positively correlated with one heavy PAH, i.e., benzo(a)-pyrene and also with the oil uptake. F2 accounted for 12.01% of total variance. Furthermore, from the observations (samples) layout on the factorial plane (F1 × F2) differential distribution can be noted. The 95% confidence ellipses were also plotted around the means and clearly show grouping of cv. Lady Claire samples in the positive and cv. Birgit samples in the negative levels of F1 which confirms previously drawn conclusions.

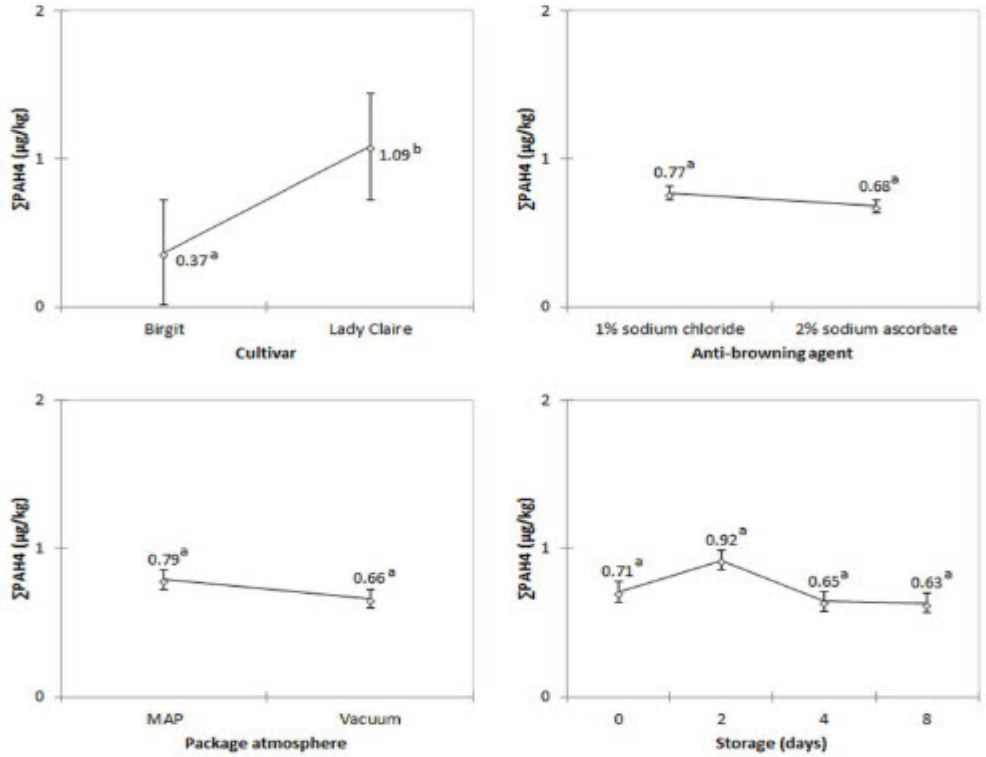

Figure 2. ΣPAH4 in fried fresh-cut potato as affected by the cultivar, anti-browning agent, packaging and storage duration. Results are expressed as mean ± SE of $n = 16$ for cultivars, anti-browning agents, package atmospheres and $n = 8$ for days. Values with different letters are statistically different at $p \leq 0.05$.

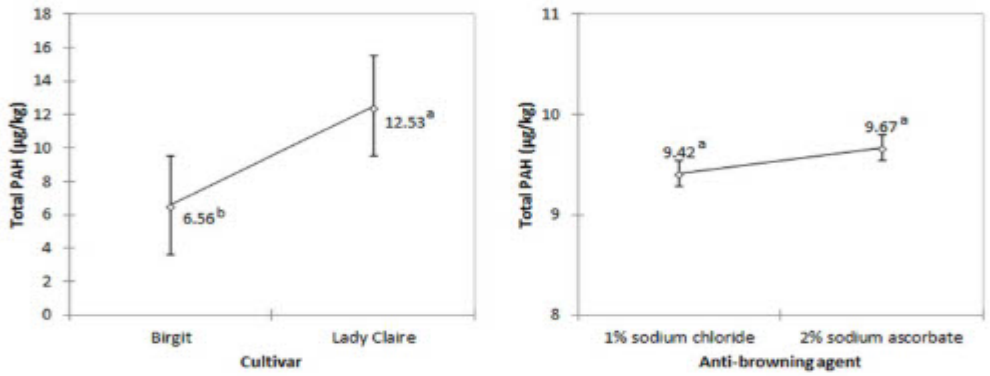

Figure 3. *Cont.*

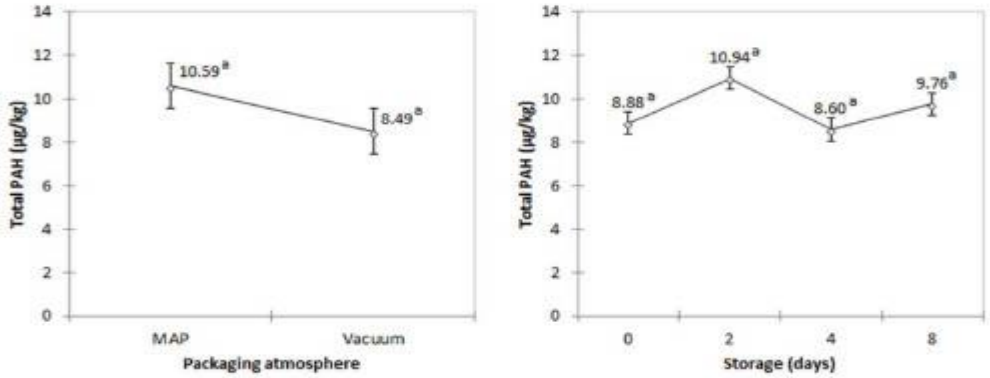

Figure 3. Total PAH in fried fresh-cut potato as affected by the cultivar, anti-browning agent, packaging and storage duration. Results are expressed as mean ± SE of $n = 16$ for cultivars, anti-browning agents, package atmospheres and $n = 8$ for days. Values with different letters are statistically different at $p \leq 0.05$.

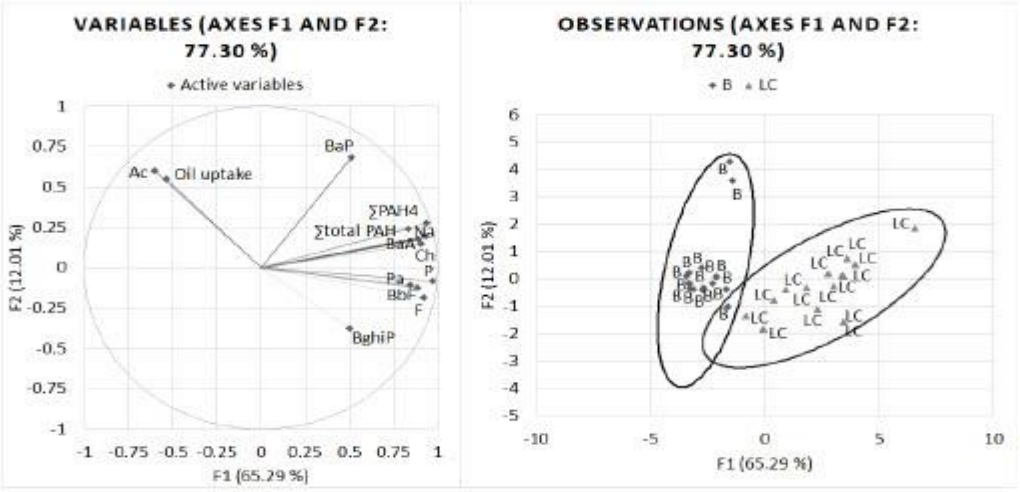

Figure 4. Principal components analysis (PCA)—Projection of active variables (Na—naphthalene, Ac—acenaphthene, F—fluorine, Pa—phenanthrene, P—pyrene, BaA—benzo(a)-anthracene, Ch—chrysene, BbF—benzo(b)-fluoranthene, BaP—benzo(a)-pyrene, BghiP—benzo(g,h,i)-perylene) and observations (B—Birgit, LC—Lady Claire) on the factorial plane (F1 × F2).

3.4. Effect of Processing

As it was mentioned, fresh-cut processing of potatoes usually includes anti-browning agent treatment and modifications of the packaging atmosphere [7,57,58]. Anti-browning agents are used to control enzymatic browning through various mechanisms that either inhibit polyphenoloxidase activity and browning reaction or react with its products causing discoloration of formed dark pigments [59]. Sodium salts used in this study were chosen due to their ability to reduce the browning products and well-established GRAS status. Even though the type of anti-browning agent can have a significant effect on the metabolic activity and sensory attributes of FCP [49,59], sodium chloride and sodium ascorbate solutions used in this work did not cause any significant changes to the content of PAH.

Furthermore, packaging solutions applied in this work, i.e., VP and MAP are, due to their inhibitory effect on foodborne pathogens, often used for FC products preservation and stabilization [60].

It has been shown that VP can extend shelf-life of FCP up to 7 days without any quality deterioration taking place [61] and that it is superior to MAP in the preservation of slices appearance [9]. Even though PAH4 and total PAH levels (Figures 2 and 3) were not influenced by processing, levels of some PAH species determined in this study were affected by the packaging atmosphere. Naphthalene, fluorene and pyrene (Table 3) were significantly lower in potato samples kept in VP ($p = 0.04$, $p = 0.03$ and $p = 0.02$, respectively) in comparison to the MAP ones. These differences could be supported by the results of Rocha et al. (2003) [61] which showed that VP of potatoes causes mechanical damage of the potato tissue and results in 25% decrease in firmness in the first day of storage. This cell destruction might have caused a more significant migration of PAH species to the frying oil and therefore lowered their contents in the fried FCP slices. Furthermore, naphthalene, fluorene, phenanthrene and benzo(a)pyrene (Table 4) were also affected by the interaction of cultivar and packaging atmosphere ($p = 0.01$, $p = 0.03$, $p = 0.01$ and $p = 0.02$, respectively). PAH levels were generally higher in cv. Lady Claire samples stored in MAP compared to the VP samples. Considering that cv. Lady Claire fresh potatoes had higher lipid content, this notion adds to the previous explanation of some PAH levels being decreased by the effect of vacuum.

Treated and packaged FCP were stored up to 8 days. This period was selected based on the results of Dite-Hunjek et al. (2020) [13] study which showed that basic quality and sensory properties of FCP remained preserved during 8 days of storage. As expected, storage duration (0–8 days) did not show any significant effect on the content of analysed PAH.

4. Conclusions

Results of this study showed that minimal processing did not increase the oil content of fried FCP. Among all analysed factors, only cultivar had a significant effect on the oil uptake which was higher in cv. Birgit potatoes. Compared to the cv. Lady Claire, cv. Birgit had higher tuber water content, consequently causing higher interchange of water with frying oil. Based on the comparison with the EU legal limitations, findings of the present study of benzo(a)pyrene and ΣPAH4 levels up to 0.62 and 1.36 μg kg^{-1} respectively, confirmed previously established notion that PAH contamination in fried potatoes does not pose a direct health hazard to the consumer. Also, as PAH contamination from frying oil and PAH formation during frying process is negligible, environmental pollution is the most probable source of PAH in fried potato slices. Potato cultivar had a significant influence on the content of the majority of examined light and heavy PAH species with the exception of anthracene, fluoranthene, benzo(k)fluoranthene and dibenzo(a,h)anthracene. While the anti-browning treatment did not cause any changes in the PAH levels, naphthalene, fluorene, and pyrene were decreased by VP probably due to the mechanical damage of the potato tissue. No significant differences were determined between the PAH levels during storage, therefore regarding this parameter, storage of FCP produced with applied processing conditions can be safely achieved through the whole tested time span, i.e., up to 8 days. However, due to the potential cumulative exposure, certain caution must be advised. In addition, as risk assessment in FC products is presented not only by PAH levels, but also by other parameters such as microbial load, FCP production requires great attention focused on product's safety during the entire production process.

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Chapter 6

General discussion

- **Influence of cultivar, ABA, packaging atmosphere, storage temperature and storage time on quality and sensory properties of raw and boiled MPP**
- **Influence of cultivar, tubers aging, ABA, packaging atmosphere and storage time on quality, sensory properties and shelf-life of raw and cooked MPP**
- **Influence of cultivar, tubers aging, storage time and cooking method on the phenolics, sugars and acrylamide content of MPP**
- **Effect of cultivar, anti-browning treatment and storage conditions on oil uptake and Polycyclic Aromatic Hydrocarbons (PAHs) in minimally processed potato**
- **Statistical analysis**

1. Influence of cultivar, ABA, packaging atmosphere, storage temperature and storage time on the quality and sensory properties of raw and boiled MPP

The aim of the research presented in the *Publication No. 1* was to investigate which cultivars, natural, potentially non-toxic and easily available ABA, packaging atmosphere and storage conditions can contribute the most for preserving the quality of MPP and extend its shelf life. In this part results presented in *Publication No. 1* will be discussed. In the research, the table potato cv. Birgit and the industrial potato cv. Lady Claire were used. Potato slices were prepared and treated with ABA, i.e. 1% SC, 2% SA solution and water as a control. The potatoes were packaged in a VP, active MA (10% CO_2, 3% O_2 and 87% N_2) and passive MA. VP and active MA samples were packaged in the bags made of bi-layer laminate of PA/PE: ribbed layer PA 30 μm/PE 70 μm, and flat layer PA 30 μm/PE 100 μm. Samples packaged in passive MA were packed in PE bags (45 μm) and served as control. MPP samples were stored at 3 and 10 °C for 10 days and analyzed during 0, 2^{nd}, 4^{th}, 8^{th}, and 10^{th} day of storage. Physical and chemical properties of samples were analyzed, i.e. dry matter content, pH, color and texture properties, gas composition within packages, microbial activity and sensory properties of raw and boiled MPP.

Based on the results it can be concluded that cv. Birgit was more acceptable for minimal processing when compared to cv. Lady Claire although the differences in results were not remarkable (*Publication No. 1* - Figure 1). The dry matter content and pH was slightly lower in cv. Birgit when compared to cv. Lady Claire (*Publication No. 1* - Table 1) which is a cultivar characteristic. Cv. Birgit contains a middle amount of dry matter in comparison with other cultivars, while cv. Lady Claire contains a high amount of dry matter (Halford et al., 2012; European Cultivated Potato Database, 2017). Cv. Lady Claire color parameters *L**, *a** and *b** were lower when compared to cv. Birgit samples (*Publication No. 1* - Table 1). Higher *L** values confirms that cv. Birgit was less prone to browning, while higher *b** values show that color of its flesh was more shifted towards the yellow part of the spectrum. A lower tendency to brown is a desirable characteristic of MPP (Tudela and Gil, 2020), therefore the above results also indicated that cv. Birgit was more suitable for the production of MPP. The results of texture parameters suggested that values for firmness, elasticity, and work required to chew did not significantly differentiated ($p \leq 0.05$) between cultivars (*Publication No. 1* - Table 1). The CO_2 level was higher in packages with cv. Lady Claire samples (*Publication*

No. 1 - Table 1). High proportion of CO_2 indicates higher respiration rate of the cultivar which is an undesirable characteristic of potatoes for minimal processing since it causes the shorter shelf-life of the product (Rocculi et al., 2009). The panelists rated raw samples cv. Birgit better than samples of cv. Lady Claire in terms of color, characteristic odor and absence of off-odor (*Publication No. 1* - Table 2). Cv. Birgit was rated as moister which also goes in favor of the cv. Birgit since consumers do not prefer dried and hard potato slices (Rocculi et al., 2009).

The ABA had a statistically significant effect on the most of analyzed parameters. The highest *L** and *b** values, and the lowest *a** value (*Publication No. 1* - Table 1) measured on the samples treated with SA indicated that SA was more effective ABA in comparison with SC. SC-treated samples had the highest dry matter content and the highest pH most likely due to SC ability to absorb water and pH value of SC solution.Contrary, the water-treated samples had the lowest dry matter content and the lowest pH probably due to endogenous enzymes activations on the cell walls and growth of microorganisms (Rocha et al., 2003).The firmness and work required for chewing were the highest in the samples treated with SC which also indicated that SC treatment led to hardening of texture of MPP, like calcium chloride (Bobo-García et al., 2020). The highest CO_2 content was determined in SC-treated samples which indicated increased respiration of potatoes and consequently a tendency to spoilage. Based on the results of sensory analysis, the samples treated with SA were the least browned and had the best preserved characteristic odor of the product with the least impurities of off-odor. Also, the panelists concluded that the firmness of the samples treated with SA and SC was almost the same. The presence of off-odor was the most noticeable in the samples treated with SC, and these samples were rated as the moistest, while the greatest browning of the samples, absence of a characteristic odor and the lowest moistness were observed in water-treated samples. Due to convincingly unsatisfactory results for physical, chemical and sensory parameters obtained for water-treated samples, the impact of water-treatement in further research was no longer considered not even as a control.

VP proved to be the best option for MPP packaging. Although the color of the potatoes was well preserved in the active MA (the highest *L** and *b** parameters), the samples packaged in active MA had the lower dry matter, their pH increased, and the results of sensory analysis showed that they had the most pronounced off-odor (*Publication No.1* - Table 1). This can be associated with reduced O_2 content in the active MA package (0.96 ± 0.02%). Such almost anaerobic conditions could cause the formation of ethanol and acetaldehydes, and off-flavors, respectively (Gorris and Peppelenbos, 1992; Cacace et al.,

2002).The samples packaged in VP had the best preserved color of the product, the highest moistness and better preserved characteristic odor of the product when compared to the samples packaged in active MA. Samples packaged in passive MA indicated typical signs of browning and spoilage (the lowest parameters *L** and *b** and the highest value of parameter *a**, the highest value of firmness and work required to chew the samples) (*Publication No. 1* - Table 1). As stated in the theoretical part of the dissertation, numerous scientists have compared the shelf-life of MPP packaged in VP and MA (Beltrán et al., 2005; Pineli et al., 2005) and confirmed that vacuum is a more suitable packaging atmosphere to preserve the durability of MPP in comparison with packaging in active MA. Because the results for physical and sensory parameters of samples packaged in passive MA were less satisfactory, the impact of passive MA on these parameters was no longer examined not even as a control.

Storage temperature had a statistically significant effect ($p \leq 0.05$) on dry matter and firmness of the product as well as O_2 and CO_2 level in the package. Samples stored at 3 °C had higher dry matter content and higher firmness when compared to samples stored at 10 °C (*Publication No. 1* - Table 1). The O_2 content was higher in the samples stored at 3 °C, while CO_2 content was higher in the samples stored at 10 °C indicating a higher respiration rate of samples stored at higher temperature (Ghazavi and Houshmand, 2010). Cacace et al. (2002) measured the O_2 and CO_2 concentration in MPP stored at 1 and 6 °C and also concluded that the respiration rate was higher in samples stored at higher temperature. Storage temperature did not have a statistically significant influence ($p > 0.05$) on MPP color parameters. Contrary, storage temperature had a statistically significant influence ($p \leq 0.05$) on the sensory evaluated color and the presence of off-odor in the raw samples. At higher temperature, a less browning and just slightly higher presence of off-odor was observed in the samples. However, samples stored at 10 °C were microbiologically correct. Principal Component Analysis (PCA) (*Publication No.1* - Figure 1) did not show the grouping of the examined samples by temperature of storage. Since MPP are more likely to be stored in retail at temperatures close to 10 °C, further research was focused on monitoring product quality parameters and shelf-life at temperature of 10°C and the influence of storage temperature of 3 °C on these parameters was no longer examined.

The storage time significantly affected ($p \leq 0.05$) almost all analyzed parameters. The dry matter content decreased during time most likely due to starch degradation and decomposition in soluble sugars (Wustman and Struik, 2007; Ierna et al., 2017). The pH of the sample also decreased during storage. Although color parameters slightly varied during storage, significant increase of *L** values and decrease of *b** values occurred at the beginning of the

storage. The firmness and work required for chewing increased during storage time most likely due to water loss of the peeled and sliced sample and already mentioned wounding response (Rocculi et al., 2009). The O_2 content decreased during storage until the 8th day after which it began to rise, while CO_2 content continuously increased. The CO_2 content increase also affected the lowering of the pH of the samples during storage.The largest changes in the concentration of O_2 and CO_2 were recorded until the 4th day of storage, after which their level was stable similary to the results of Beltrán et al. (2005). In their research stable levels of gases were recorded after 5 days of storage at 4 °C of ABA treated cv. Monalisa packaged in LDPE and passive MA or VP. The results of sensory analysis indicated that during storage the samples turned brown and lost their characteristic odor, while off-odor appeared, especially after the 8th day of storage.

Microbiological analysis was performed in all samples and the presence of aerobic mesophilic bacteria and *Enterobacteriaceae* was examined. According to the Guide Microbiological Criteria for Food (Ministry of Agriculture, Fisheries and Rural Development of the Republic of Croatia, 2009) "ready to eat" samples that have >10^5 aerobic mesophilic bacteria and >10^3*Enterobacteriaceae*are considered microbiologically defective. By the 8th day of storage, most of the samples met the criteria recommended by the Guide, except the samples packaged in MA and stored at 3 °C (*Publication No. 1* - Table 5). Samples stored at 10 °C were microbiologically correct, most likely due to low level of O_2 in the package, since in the absence of O_2, the growth of aerobic mesophilic bacteria is prevented (Putnik et al., 2016).

In addition to the sensory properties of the raw samples (*Publication No. 1* - Table 2), samples after boiling were also sensory evaluated (*Publication No. 1* - Table 3). Sensory characteristics that were evaluated in boiled samples were: color (browning intensity), characteristic odor, off-odor, moistness, firmness, creaminess and characteristic taste as well as sweet, sour, salty, bitter and off-taste.

The sensory results of boiled samples also confirmed that cv. Birgit was more acceptable for MPP production as it was better rated in terms of all sensory characteristics. Cv. Birgit samples had less pronounced browning, more pronounced characteristic odor and taste, and less pronounced off-odor when compared to cv. Lady Claire samples. Also, cv. Birgit samples were characterized with less firmness and more pronounced creaminess. Moreover, the sweetness was more pronounced in cv. Birgit samples, while cv. Lady Claire samples showed more pronounced bitter taste and off-taste.

ABA had a statistically significant ($p \leq 0.05$) effect on color, sweet taste and off-taste of boiled samples where samples treated with water were rated with the lowest scores. Samples treated with SA were rated as the samples least prone to browning. Also, these samples were evaluated as samples with the most pronounced sweet taste and the least pronounced off-taste.The results of other sensory parameters were not statictically influenced by examined ABA, although numerically the characteristic taste of the samples treated with SA was the best evaluated. Package atmosphere significantly ($p \leq 0.05$) influenced only on color, off-odor, firmness, sour taste and off-taste where samples packaged in VP were the best evaluated in terms of color and the absence of off-odor. The highest presence of off-odor, firmness, sour taste, and off-taste was recorded in samples packaged in active MA.

Different storage temperatures did not have a statistically significant effect ($p > 0.05$) on the sensory characteristics of the boiled samples. The largest difference in the results was visible in the evaluation of the color, firmness and creaminess of the samples. Samples stored at 10 °C were rated as ones with higher firmness and creaminess and less prone to browning.

The storage time had a statistically significant influence ($p \leq 0.05$) on all examined sensory properties of MPP. As storage time increased, the samples became more prone to browning, the characteristic odor and taste were less pronounced, while the presence of off-odor and off-taste was more noticeable. The firmness of the samples and the presence of sour taste and bitter taste increased over time, while creaminess and sweet taste decreased.

When comparing the results of sensory analysis of raw and boiled potatoes, it can be seen that boiled potatoes were better rated in terms of the presence of characteristic odor and the absence of off-odor. Off-odor is contributed by volatiles and it is possible that they evaporated during boiling while volatiles that are responsible for creating a characteristic odor can be formed during boiling from amino acid precursors and sugars with nucleotides as potentiators (Thybo et al., 2006; Jansky, 2010). According to all obtained results, water-treatment, passive MA and 3ºC were not further investigated and in further studies, potatoes were stored up to 8 days.

2. Influence of cultivar, tubers aging, ABA, packaging atmosphere and storage time on quality, sensory properties and shelf-life of raw and cooked MPP

In *Publication No.2*, in addition to the influence of already mentioned parameters (cultivar, ABA, packaging atmosphere, storage time),the greatest focus was on influence of tubers age on the quality and sensory properties of raw, and subsequently boiled, fried and baked MPP samples. After harvest, cv. Birgit and Lady Claire potatoes were stored in cool and dark place in storage house at temperature of 8 °C, relative humidity approximately 100% and they were treated with anti-sprouting agents (Gro Stop Basis and Gro Stop Fog). Three days before processing, potatoes were stored at 16 °C. During the 1st, 5th and 9th month of storage, tubers were used for minimal processing. Tubers were peeled, sliced and treated with 1% SC and 2% SA, packaged in VP and MA (10% CO_2, 3% O_2 and 87% N_2) and stored at 10 °C for 8 days. Samples were packaged in PA/PE bags with film thickness 90 μm for VP (permeability at 23 °C and RH 0% for O_2 was 8.21 $cm^3m^{-2}day^{-1}bar^{-1}$) and PA/PE bags with film thickness 75 μm were used for MAP (permeability for O_2 was 22.3 $cm^3\ m^{-2}\ day^{-1}\ bar^{-1}$). Such conditions were selected based on the results obtained in *Publication No.1*. MPP samples were analyzed on the 0, 2nd, 4th and 8th day of storage for weight loss, total solids (TS) and soluble solids (SS), pH, color, texture and sensory properties of raw, boiled, fried and baked MPP. The O_2 and CO_2 content was also measured within the packages.

Results in *Publication No. 2* were in accordance with the results presented in *Publication No. 1* where it was concluded that cv. Birgit is more acceptable for minimal processing when compared to cv. Lady Claire. (*Publication No. 1* - Figure 1; *Publication No. 2*-Figure 1). The values for TS, SS and pH were slightly lower in cv. Birgit MPP when compared to cv. Lady Claire samples (Publication *No. 2* - Table 1) due to previously mentioned cultivar characteristics. The color parameters *L**, *a**, *b** and *C** were lower in cv. Lady Claire samples in comparison with cv. Birgit samples. *H°* parameter was higher in cv. Birgit samples (*Publication No. 2* - Table 2) which is in line with the results reported in *Publication No. 1*. The firmness and elasticity of the MPP samples were statistically significantly different ($p \leq 0.05$) among cultivars, where cv. Lady Claire samples had higher firmness and elasticity in comparison withcv. Birgit samples. Thiswas in accordance with results for TS and SS. These results are in favor of the cv. Birgit as consumers do not prefer hard potato slices (Rocculi et al., 2009). The average value of the CO_2 content was higher in the samples of cv. Birgit. In *Publication No. 2*, as in *Publication No. 1*, the panelists rated raw

samples of cv. Birgit better than cv. Lady Claire samples in terms of color, characteristic odor and absence of off-odor.

Publication No. 2 was mainly focused on the influence of tubers aging on the physical and sensory parameters of MPP (*Publication No. 2* - Tables 1, 2 and 3; Figure 2). With increase of tubers age, pH and TS content in MPP decreased and SS increased. The interraction cultivar *vs.* tubers age indicated a reduced content of TS in the MPP of cv. Birgit and a decrease in the TS content during aging of cv. Birgit tubers. During storage of tubers, starch converts into sugars due to respiration, which could explain the decrease in TS and the increase in SS (Wustman and Struik, 2007). MPP weight loss was most noticeable during the 1st and 9th month of tubers age. Weight loss decreased due to transpiration and respiration, and it was more intense in the 1st month of storage due to stress caused by harvesting and adaptation to new storage conditions. Further decrease in weight loss during the last months of storage could be a result of possible interruption of dormancy and sprouting, during which the starch is converted into sugars (Wustman and Struik, 2007; Rotim, 2010). Considering respiration, such trend was not observed in O_2 and CO_2 level in MPP during tubers aging. This could be explained by peeling and cutting by itself, which influence respiration (Limbo and Piergiovanni, 2006). Namely, in the 5th month of tubers storage O_2 level was slightly lower and CO_2 slightly higher then in the samples from the 1st and 9th month what indicated a higher respiration of MPP produced from 5th month old tubers. MPP storage time had significant impact ($p \leq 0.05$) on all examined parameters (*Publication No. 2* - Table 1). TS content decreased during time, while SS increased what is most likely due to starch degradation and decomposition in soluble sugars (Wustman and Struik, 2007; Ierna et al., 2017). After the 4th day, weight loss declined, what is similar with published data in study of Rocha et al. (2003), as well as pH. The O_2 content decreased during storage, while CO_2 content increased.

Color parameters *L**, and *H°* decreased during tubers aging, while *a**,*b**, and *C** increased which indicated a tendency of samples to browning. The texture parameters (firmness, elasticity and work required for chewing) increased with the age of tubers, what could most likely be due to already mentioned wounding response and transpiration (Rocculi et al., 2009). Similar observations could be applied to the results for color and texture for both cutivars according to the interactions cultivar *vs.* tubers age (*Publication No. 2*- Table 2). Based on the results for sensory analysis of raw MPP, during tubers aging MPP samples were more prone to browning, more moistness and less firm. Interactions of cultivar *vs.* tubers age also indicated similar results for both cultivars, although tendency to browning during aging of tubers was more visible in cv. Lady Claire MPP as well as appearance of off-odor.

ABA had a statistically significant effect ($p \leq 0.05$) on most of the measured color parameters. SA has been shown to be more effective in color preservation since higher *L** and *b** values, and lower *a** values were obtained in SA-treated samples (*Publication No. 2* - Table 2).This is similar to the results presented in *Publication No.1*. The same results were presented by the interactions of tubers age *vs.* ABA, where similar trend in both cultivars could be observed. ABA had no significant impact ($p > 0.05$) on texture parameters. Based on the results for sensory analysis, it was concluded that the samples treated with SA had the best preserved color and characteristic odor what is similar to the results in the first research (*Publication No.1*). ABA did not have a statistically significant influence ($p > 0.05$) on the moistness, firmness and presence of off-odor.

Furthermore, obtained results also confirmed that VP was the best option for MPP packaging. Although in the both studies the color of the potatoes was well preserved in active MA packages (the highest *L** and *b** parameters), the samples packaged in active MA had lower firmness and TS content, higher pH and the most pronounced off-odor (*Publication No. 2* - Tables 1 and 2). According to the results for sensory analysis, the samples packaged in VP had the best preserved color, the highest moistness and better preserved characteristic odor of the product when compared to the samples packaged in active MA. The same observations were also reported in the *Publication No. 1*.

The MPP storage time had significant impact ($p \leq 0.05$) on color parameters as well as on elasticity and work. During MPP storage, *L**,*b**, *C**and *H°* values decreased by the end of storage,while *a** values slightly varied. The elasticity and work required for chewing increased during storage time. The results for sensory analysis in both studies indicated that the samples were more prone to browning, and to losing characteristic odor as well as to appearing off-odor during MPP storage. Also, during MPP storage the moistness and firmess decreased probably due to activity of endogenous enzymes (Rocha et al., 2003).

Sensory characteristics that were evaluated in boiled samples (*Publication No. 2*- Table 4) were: color (browning intensity), characteristic odor, off-odor, moistness, firmness, creaminess and characteristic taste as well as sweet, sour, salty, bitter and off-taste.

The sensory results for boiled samples are in accordance with the results reported in *Publication No. 1*. Namley, cv. Birgit is more acceptable for MPP production as it was better rated in terms of almost all evaluated sensory characteristics. Samples of cv. Birgit had significantly ($p \leq 0.05$) less pronounced browning and off-taste as well as more pronounced moistness, creaminess and characteristic taste in comparison with cv. Lady Claire samples.

Sensory characteristics such as characteristic odor, firmness, sweet and sour taste were rated equally for both cultivars.

Tubers age had a statistically significant influence ($p \leq 0.05$) on the browning, moistness, salty, sour, bitter and off-taste. Characteristic taste declined after the 5th month. The interactions cultivar *vs.* tubers age indicated that cv. Lady Claire was more prone to browning, to appearance of sour and off-taste and these parameters increased during tubers aging. According to Jansky (2010), potato aging has no negative impact on potato flavor, although the best rated samples were potatoes up to 5 months old according to sensory analysis of MPP.

The samples treated with SC and SA were equally evaluated in terms of color. The samples treated with SC were slightly better evaluated in almost all examined attributes when compared to samples treated with SA. This is opposite to the results obtained in the first study presented in *Publication No. 1*, but the numerical differences were very slight in both studies. Moreover, in both studies, samples packaged in VP were best rated in terms of color, characteristic odor and taste, and the absence of off-odor. In the samples packaged in active MA the highest presence of off-odor, moistness, firmness, sour taste, bitter taste and off-taste was recorded.

The MPP storage time had a statistically significant influence ($p \leq 0.05$) on all examined sensory properties, as in the first study (*Publication No. 1*). As storage time increased, the samples were more prone to browning, the characteristic odor and taste were less pronounced and the presence of off-odor and off-taste were more noticeable. The firmness of the samples, creaminess and sweet taste decreased, and the presence of sour taste and bitter taste increased over time.

As in *Publication No. 1*, boiled samples were rated better than raw samples in terms of the presence of characteristic odor and the absence of off-odor.

In the *Publication No. 2*, sensory properties of fried and baked samples were also evaluated. In fried and baked samples, color (tendency to brown), characteristic odor and off-odor, oiliness, firmness, crispiness, characteristic taste, sweet, salty, sour, bitter and off-taste were evaluated (*Publication No. 2* - Tables 5 and 6; Figure 3).

Fried and baked samples of cv. Birgit were better evaluated in terms of less tendency to brown, more pronounced characteristic odor and less pronounced salty and bitter taste. Samples of cv. Lady Claire were rated as less oily, more harder, and crispier than cv. Birgit samples, which is consistent with cultivar characteristics. Cv. Lady Claire is an industrial potato cultivar grown primarily for the production of chips.

Tubers aging significantly influenced ($p \leq 0.05$) on almost all examined sensory attributes of fried and baked samples, but not on color of fried ones, and characteristic odor and taste of fried and baked samples. Although there was a significant influence of tubers aging on browning among baked samples, numerical differences were negligible. By increase of potatoes age, oiliness, sour, bitter and off-taste were more pronounced in fried and baked MPP, while off-odor, firmness (only in fried samples), crispiness, sweet and salty taste were less noticeable.

Fried and baked samples treated with SC were less prone to browning and were less scored for off-odor, oiliness, bitter (only in baked) and off-taste (only in fried) as well as they better retained characteristic taste. Packaging atmosphere significantly influenced ($p \leq 0.05$) only color, characteristic and off-odor, and crispness in fried and baked samples as well as salty (in fried) and bitter (in baked) taste. All listed changes were less pronounced in VP samples with exception of crispiness in baked ones. Further research was conducted on SA-treated and VP samples, as raw MPP samples treated in this way were the least prone to browning which is one of the key parameters of MPP quality.

Storage time significantly influenced ($p \leq 0.05$) on almost all examined sensory attributes of fried and baked MPP. All changes mostly had negative impact on sensory quality, although all samples remained acceptable till the 8th day.

Generally, grand means of all desirable attributes were higher for fried MPP when compared to baked ones and inversely, grand means of all undesirable attributes were lower for fried MPP in comparison with baked ones. Therefore, for further study only fried MPP were investigated.

3. Influence of cultivar, tubers aging, storage time and cooking method on the phenolics, sugars and acrylamide content of MPP

In the *Publication No. 3*, the influence of cultivar, tubers aging, MPP storage time and cooking method on the content of phenolics, sugars and acrylamide in MPP was examined. Samples of cv. Birgit and Lady Claire stored for 1, 5 and 9 months were peeled, sliced, treated with 2% SA solution and packaged in VP. These conditions were selected based on the results in *Publications No. 1 and 2*. Thereafter, the MPP were stored for 8 days at 10 °C. During the 1st, 5th and 8th day of storage, samples were boiled or fried and then analyzed. The content of phenolics (catechin, epicatechin, chlorogenic acid and total phenolics) and sugars (fructose,

glucose, sucrose and total sugars) was determined in raw, boiled and fried samples. Phenolics were analyzed by UPLC MS2 and sugars using HPLC. Acrylamide was determined only on fried samples byUPLC MS2.

Cv. Lady Claire had a significantly higher concentration ($p \leq 0.05$) of total and individual phenolics (total phenolics 10.13 mg 100 g^{-1} DW; catechin 0.172 mg 100 g^{-1} DW; epicatechin 0.337 mg 100 g^{-1} DW; chlorogenic acid 9.63 mg 100 g^{-1} DW) when compared to cv. Birgit (total phenolics 5.77 mg 100 g^{-1} DW; catechin 0.168 mg 100 g^{-1} DW; epicatechin 0.298 mg 100 g^{-1} DW; chlorogenic acid 5.30 mg 100 g^{-1} DW) (*Publication No. 3* - Table 1; Figure 1). Deuβer et al. (2012) also concluded that content of phenolics depends on potato cultivar. Chlorogenic acid was the most abundant, while catechin was the least abundant what is in accordance with studies of Deuβer et al. (2012) and Akyol et al. (2016).

Content of total and individual phenolics was the highest during the 1st month of tubers storage and it decreased significantly until the 5th month of storage when it was the lowest (except for epicatechin, which was the lowest during the 9th month of potato storage). From the 5th to the 9th month of storage, total and individual phenolics increased again. The same influence of cultivar and tubers age was also observed by interaction cultivar *vs.* tubers age (*Publication No.3* - Table 1; Figure 2). Some scientists stated that level of phenolics decreases after harvesting and it increases again during the entire period of cold storage (Külen et al., 2013). Akyol et al. (2016) claimed that phenolics increased or remained at the sam level during cold storage (4 °C), while Andre et al. (2009) stated that phenolics decreased during storage of potatoes at 10 °C.This change in phenolics is influenced not only by temperature but also by storage time, i.e. each parameter that cause a stress to the plant. Therefore, the phenolics were the highest during harvesting and they decreased until the 4th month of storage when potatoes were in the dormancy phase and they were not under stress. However, after that period, phenolics increased again (Külen et al., 2013). Results of this study are in accordance with such findings.

During MPP storage, total and individual phenolics decreased (*Publication No.3* - Table 1). A possible cause of this occurence is participation of phenolics, particularly chlorogenic acid, as substrates in enzymatic browning reactions (Amaki et al., 2011, Narváez-Cuenca et al., 2013; Li et al., 2018; Licciardello et al., 2018).

The interaction cultivar *vs.* storage time showed that phenolics were higher in cv. Lady Claire in comparison with cv. Birgit, except in the case of catechin.Their content decreased during storage, although in some samples the content of phenolics was the lowest during the 5th day of storage.The results also showed that total phenolics and chlorogenic acid (known as

the browning substrate) decreased faster in cv. Lady Claire samples, cultivar more prone to enzymatic browning. The interaction storage time *vs.* tubers age indicated that in MPP made from tubers aged 1 and 9 months phenolics decreased during 8 days of storage, while in MPP made from tubers of 5 months age phenolics increased until the 5^{th} day of storage and then they decreased again.

Phenolics were the highest in raw samples, except for epicatechin. Boiling caused the highest decrease of phenolics. The same trend was observed by interaction cultivar *vs.* cooking method. The decrease in phenolics content during boiling is most likely influenced by cell walls rupture, leakage of phenolics and their solubility in water as well as their degradation at high temperature (Tian et al., 2016).

The interaction cooking method *vs.* tubers age showed that the lowest phenolics were present in MPP produced from tubers of 5 months age and in boiled samples.The interaction cooking method *vs.* MPP storage indicated that phenolics decreased in both boiled and fried samples during MPP storage.

The content of total and individual sugars was higher in cv. Birgit (total sugars1.75 g 100 g^{-1} DW; fructose 0.321 g 100 g^{-1} DW; glucose 0.373 g 100 g^{-1} DW; sucrose 1.06 g 100 g^{-1} DW) when compared to cv. Lady Claire (total sugars 0.65 g 100 g^{-1} DW; fructose 0.140 g 100 g^{-1} DW; glucose 0. 178 g 100 g^{-1} DW; sucrose 0.33 g 100 g^{-1} DW) which is cultivar characteristic. Cv. Birgit is a table potato, while cv. Lady Claire is an industrial potato intended for the chips production, so it is extremely important that it contains low content of sugars as possible (Elmore et al., 2015; European Cultivated Potato Database, 2017; Norika GmbH, 2020;).

Furthermore, total and individual sugars increased during tubers aging. The increase was higher in cv. Birgit in comparison with cv. Lady Claire. In both cultivars, sucrose content was the highest. The interaction cultivar *vs.* tubers age also showed that during tubers aging sugars increased more in cv. Birgit than in cv. Lady Claire (*Publication No.3* - Table 1; Figure 2). Namely, during aging of tubers, breakdown of starch into sucrose occurs due to respiration and afterwards sucrose decomposes into reducing sugars (glucose and fructose) in order to use them for energy. Moreover, in cases that cause stress for the tuber (inadequate storage conditions such as low storage temperature or high CO_2 content) accumulation of sugars in potato tubers can be enhanced. Sugars accumulate in tubers due to interruption of dormant state and appearance of sprouts. During sprouting, tubers are prepared to feed the new plant and therefore starch is converted into simple sugars (glucose and fructose) (Wustman and Struik, 2007; Kaul et al., 2010).

During MPP storage, the content of sugars was the highest during the 1st day and it decreased until the 5th day of storage. From the 5th till the 8th day of storage, the content of sugars rised again (*Publication No.3 -* Table 1). Immediately after minimal processing, i.e. peeling, cutting, treatment with ABA and packaging, potatoes are in a state of stress due to which they accumulated sugars. The accumulated sugars were consumed in the following days due to respiration, but later starch probably decomposed and sugars increased (Vreugdenhil, 2007; Wustman and Struik, 2007).

The interaction cultivar *vs.* MPP storage showed that sugars generally increased in cv. Birgit during storage,while cv. Lady Claire showed a decreasing trend during storage of MPP. MPP storage *vs.* tubers age did not show statistically significant effect ($p>0.05$) on the content of all analyzed sugars (*Publication No.3 -* Table 1). In general, the results showed that as the tubers age and storage day increased, the sugars also increased. Despite the increase in sugars, these values were still low enough not to affect product quality.

The cooking method had a statistically significant effect ($p\leq0.05$) on fructose, sucrose and total sugars which were the highest in raw potatoes and the lowest in boiled potatoes. The cultivar *vs.* cooking method showed that content of sugars was the highest in raw samples and the lowest in boiled samples except in the case of fructose in cv. Lady Claire samples. It was the lowest in raw samples and the highest in fried samples (*Publication No.3 -* Table 1; Figure 3). The lowest sugars were in boiled samples because during boiling the cell walls are damaged, sugars come out of the cells and they dissolve in water in which the potatoes are boiled (Pedreschi et al., 2009; Zhang et al., 2018). During frying, sugars also decrease due to their participation in Maillard's reactions (Jansky, 2010).

Cooking method *vs.*tubers age indicated that sugars were generally the lowest in boiled samples, except in the case of glucose which was the lowest in fried MPP made from potatoes stored for 9 months. Independently of cooking method, sugars increased during aging of tubers.

Storage time *vs.* cooking method showed that sugars increased in fried samples during MPP storage and they decreased in boiled samples with the lowest values on the 5th day (*Publication No.3 -* Table 1).

Higher acrylamide content was present in cv. Birgit (1025.87 µg kg^{-1} DW) in comparison with cv. Lady Claire (331.75 µg kg^{-1} DW). Concentration of acrylamide increased with potato aging and MPP storage time. Cultivar *vs.* tubers age, cultivar *vs.* storage time and storage time *vs.*tubers age also showed that concentration of AA increased with tubers aging and MPP storage time, which was more present in cv. Birgit (*Publication No. 3-*

Table 2). Moreover, AA positively correlated with sugars (a strong correlation between AA and fructose (r_s = 0.62), glucose (r_s = 0.79), sucrose (r_s = 0.62) and total sugars (r_s = 0.76). Also, it can be seen that by prolonging the MPP storage, there was a negative correlation between AA and total phenolics as well as chlorogenic acid. In research of Zhu et al. (2010) and Kalita et al. (2013) similar correlation was observed. The results for AA are expressed as μg kg^{-1} DW, which means that the same values expressed in μg kg^{-1} fresh weight are up to 3-fold lower. Therefore, it can be concluded that all results meet EC (2017) regulation which states 750 μg kg^{-1} fresh weight as the reference value for the acrylamide content.

4. Effect of cultivar, ABA treatment and storage conditions on oil uptake and PAHs in MPP

In *Publication No. 4*, the influence of cultivar, ABA and MPP storage conditions on oil uptake and PAHs level was examined. Cv. Birgit and Lady Claire samples were peeled, sliced, treated with 1% SC solution and 2% SA solution and packaged in VP and active MA. Packaged samples were stored for 8 days at 10 °C. During the initial, 2nd, 4th and 8th day of storage, the samples were fried in sunflower oil at 180 °C for 5 min. After frying, the oil from the samples was extracted and the oil concentration in each sample was determined. After isolation, determination and quantification of PAHs were performed. Light fractions of PAHs with 2-4 rings (naphthalene, acenaphthene, fluorene, anthracene, fluoranthene, benzo(a) – anthracene, chrysene, pyrene) and heavy fractions of PAHs with 5 and 6 rings (benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene) were detected and quantified in the extracted oil samples by gas chromatography.

Both cultivars had a statistically significant effect ($p \leq 0.05$) on the amount of oil uptake (*Publication No. 4* - Figure 1). Cv. Birgit absorbed a significantly higher amount of oil when compared to cv. Lady Claire. These results are in line with the dry matter content (*Publications No. 1* and *No. 2*), as potatoes that contain more dry matter absorb less oil during frying (Kita, 2002). The absorbed oil amounts in these samples were significantly lower (5.34 - 11.22%) than the oil amount absorbed during chips frying as the thickness of the slices in this research was 5 mm which is much thicker than chips slices and therefore their area/volume ratio was lower.

Only cultivars and package atmosphere had a statistically significant effect ($p \leq 0.05$) on the concentration of PAHs in the samples. Both light and heavy fractions of PAHs were present in higher concentrations in cv. Lady Claire. Among the representatives of light fractions, naphthalene was dominant, followed by phenanthrene, fluoranthene and acenaphthene. As for the heavy fractions of PAHs, benzo(g,h,i)perylene, benzo(b)fluoranthene, dibenzo(a,h)anthracene and benzo(a)pyrene were the most represented (*Publication No. 4* - Tables 3 and 4; Figures 3 and 4). Higher concentration of PAHs accumulates in the potato peel due to higher lipid content in comparison with the rest of the tuber as well as in vegetables that have a higher lipid content (Fismes et al., 2002). The lipid content in cv. Lady Claire was 0.77% and in cv. Birgit 0.58%, what could be the reason for greater accumulation of PAHs in cv. Lady Claire.

Package atmosphere had a statistically significant effect ($p \leq 0.05$) only on concentrations of several PAHs, namely naphthalene, fluorene, and pyrene as well as benzo(b)fluoranthene, which is a representative of the heavy fraction of PAHs (*Publication No. 4* - Tables 3 and 4; Figure 3).

The interactions cultivar *vs.* package atmosphere had a statistically significant effect ($p \leq 0.05$) on the concentration of naphthalene, fluorene, phenanthrene and pyrene from the group of light fractions of PAHs and benzo(a)pyrene from the group of heavy fractions of PAHs (*Publication No. 4* - Tables 3 and 4; Figure 3).

Considering packaging, in general, it was evident that higher concentrations of PAHs were present in the samples packaged in active MA.

According to EC (2011), the concentration of Σ PAH4 group in food (benzo(a)pyrene, chrysene, benzo(b)fluoranthene, benzo(a)anthracene) is allowed in a concentration of up to 10 μg kg^{-1}. Σ PAH4 concentrations in this study ranged from 0.28 to 1.36 μg kg^{-1}(*Publication No. 4* - Figure 2) and meet the requirements. Also, the permissible maximum concentration of benzo(a)pyrene in food is 2 μg kg^{-1} (EC, 2011). The highest measured concentration of benzo(a)pyrene in this study was 0.62 μg kg^{-1}, which also meets the requirements of the EC (2011).

Sunflower oil was analyzed before frying and the concentrations of all examined PAHs were below the detection limit. According to some authors, frying temperature of 180 °C at which potato is usually fried in the household, does not cause the formation of PAHs (Purcaro et al., 2006; Rose et al., 2015). Therefore, it can be concluded that PAHs detected in the samples originated from the tubers, i.e. the soil in which the potatoes were grown. According to Bansal and Kim (2015), root vegetables like potatoes absorb much more PAHs through the

soil than other vegetables. Wennrich et al. (2002) also found higher concentrations of PAHs in potatoes when compared to other vegetables, and concentrations of PAHs in potatoes in the research of Zhong and Wang (2002) were up to 12.54 μg kg^{-1}.

5. PCA analysis

To investigate the possible grouping of samples based on the applied conditions, a Principal Component Analysis (PCA) was performed using a correlation matrix of physical, chemical, and sensory analysis results. In *Publication No. 1* the PCA results are shown in Figure 1. where the first two components explained 43.23% of total variance. Figure 1a shows the grouping of the samples according to the cultivar. Most of the samples of cv.Birgit are located above the PC1 axis, while cv. Lady Claire samples are mostly located below the PC1 axis. Also, partial grouping of samples is visible at Figure 1e, where most of the samples analyzed during 0 and 2^{nd} day are located on the right side of the plot while samples analyzed during 8^{th} and 10^{th} days are predominantly located on the left side. On Figure 1b, 1c and 1d no grouping of samples is visible. PCA analysis was also applied in *Publication No. 2* and its results are shown in Figures 1- 3. In Figures 1 and 2 the first two components explained 40.91% of the total variance, while in Figure 3 the first two components explained 42.88% of the total variance. In Figure 1 the grouping of cv. Birgit on the positive side of PC1 axis, and cv. Lady Claire on the negative side of PC1 axis can be observed. In Figure 2 it can be noticed that most of potato samples, 1month old, are grouped on the negative side of PC2 axis, while 9 month old potato samples are grouped on the positive side of PC2 axis. In Figure 3 it can be seen that most of the fried samples are grouped on the positive side of PC1 axis, while baked samples are grouped on the negative side of PC1 axis. In *Publication No. 3* PCA analysis is shown in Figures 1- 3. The PC1 attributed to 52.85% of total variance and PC2 accounted for 25.64% of total variance. Figure 1 shows the grouping of cv. Birgit samples on the positive side of PC1 axis, while samples of cv. Lady Claire are grouped on the negative side of PC1 axis. In Figure 2, potato samples of 1 month were predominantly grouped on the positive side of PC1 axis, while other samples were grouped on the negative side of PC1 axis. In Figure 3, the raw samples were mostly grouped on the positive side of PC2 axis and boiled and fried samples were grouped on the negative side of PC2 axis. In the *Publication No. 4* the results of PCA analysis are shown in Figure 4. PC1 represented 65.29% of total variance and PC2

represented 12.01% of total variance. The grouping of cv. Birgit and Lady Claire samples according to PAHs content is clear visible.

Chapter 7

Conclusions and prospects

Considering obtained results influenced by all investigated source of variation (tuber' age, ABA, packaging, MPP storage time and temperature) cv. Lady Claire was characterized by higher TS and pH (TS=24.21%; pH=6.04) in comparison with cv. Birgit (TS=18.45%; pH=5.97). Color of cv. Lady Claire was characterized as less yellow (b^*=31.88) in comparison with cv. Birgit (b^*=40.38) as well as a^* was near the 0 in cv. Lady Claire while in cv. Birgit was slightly higher. Generally, according to L^* value cv. Lady Claire (L^*=69.32) were slightly more prone to browning than cv. Birgit (L^*=70.05). Such conclusion was proved by sensory evaluation as well. Texture of both cultivars was similar, but cv. Lady Claire was negligible firmer. Generally, cv. Birgit samples were better sensory evaluated than cv. Lady Claire.

Treatment with water was the least effective, while treatment with SA was the most effective in preserving the color according to the results of sensory evaluation. Results of colorimetric measurments among SC and SA, pointed out SA as slightly more effective. Generally, treatment with ABA had very slight and not uniform influence on TS, pH, and texture.

Mainly, VP gave slightly better results in terms of color and texture according to instrumental measurments as well as sensory evaluation while the worst results were obtained with packaging in air atmosphere.

Independetly on all investigated source of variation mostly all samples were microbiologically correct by the 8thday of storage.

Mainly, under all investigated conditions of MPP processing difference among storage temperatures at 3 °C and 10 °C didn´t have a significant role in preserving samples during 10 days.

In VP the average O_2 content was approximately 14% and CO_2 5% while in MAP O_2 content was approximately less than 2.5% and CO_2 more than 9% even close to 14 %. According to slightly higher O_2 content in the cv. Birgit MPP samples compared to the cv. Lady Claire, it seems that respiration was higher in cv. Birgit. The packages with MPP produced from 5 months old tubers had the lowest O_2 content and the highest CO_2. The same relation was observed in the packages of samples treated with SC while reverse trend was observed in the

samples treated with SA. Generally, in the MPP package the CO_2 content increased, and O_2 content decreased with storage time.

The potato aging significantly affected the physical, chemical and sensory properties such as TS and SS, pH, color (*L**, *C** and *H°*), texture (firmness) of MPP. The TS content and pH decreased by increasing tubers age (1^{st} month: TS=22.14%; pH=6.02; 9^{th} month: TS=20.98%; pH=5.98) and storage time of MPP (0 day: TS=22.75%; pH=6.23; 8^{th} day: TS=20.86%; pH=5.87).

Generally, according to sensory analysis tubers age had no significant influence on characteristic odor of raw, boiled, fried and baked potatoes and on characteristic taste of fried and baked potatoes. MPP produced from 9^{th} month old tubers were more prone to develop negative sensory atributes as off-odor, off-taste, bitter taste etc., during storage, which was less pronounced in fried samples than in bolied. The color of fried ones, and characteristic odor and taste of fried and baked samples were preserved. Also, all changes were more obviuos for cv. Lady Claire than Birgit.

According to sensory evaluation MPP produced in this study was more suitable for boiling and frying in comparison to baking.

Content of total phenolics was higher in cv. Lady Claire MPP (10.13 mg 100 g^{-1} DW) in comparison with cv. Birgit samples (5.77 mg 100 g^{-1} DW) and in both cultivars it decreased during tubers aging (mean in 1^{st} month: 14.61 mg 100 g^{-1} DW; in9^{th} month: 5.55 mg 100 g^{-1} DW) and MPP storage (mean at 0 day: 10.06 mg 100 g^{-1} DW; at 8 day: 6.49 mg 100 g^{-1} DW).

Content of total and individual sugars was higher in cv. Birgit samples (total sugars: 1.75 g 100 g^{-1} DW; fructose: 0.321 g 100 g^{-1} DW; glucose: 0.373 g 100 g^{-1} DW; sucrose: 1.06 g 100 g^{-1} DW) when compared to cv. Lady Claire MPP samples (total sugars: 0.65 g 100 g^{-1} DW; fructose: 0.140 g 100 g^{-1} DW; glucose: 0. 178 g 100 g^{-1} DW; sucrose: 0.33 g 100 g^{-1} DW) and in both cultivars it increased during tubers aging (mean of total sugars: 1^{st} month = 0.61 g 100 g^{-1} DW; 9^{th} month = 2.08 g 100 g^{-1} DW). Storage time of MPP did not significantly affect content of sugars. Phenolics and sugars were the highest in raw samples and the lowest in boiled ones.

The acrylamide content was lower in cv. Lady Claire samples (331.75 μg kg^{-1} DW) when compared to samples of cv. Birgit (1025.87 μg kg^{-1} DW). The acrylamide increased with aging of tubers and MPP storage. Content of acrylamide was in positive correlation with content of sugars. Acrylamide content in both cultivars was below the reference value (750 μg kg^{-1} of product) prescribed by EU Regulation (EC, 2017). It was observed that acrylamide and phenolics content are in negative correlation.

Higher concentration of PAHs was recorded in cv. Lady Claire MPP in comparison with cv. Birgit samples, while higher oil uptake was present in samples of cv. Birgit. Moreover, higher concentrations of PAHs were found in samples packaged in active MA. The proportion of benzo(a)pyrene and Σ PAH4 group in food (benzo(a)pyrene, chrysene, benzo(b)fluoranthene, benzo(a)anthracene) were in accordance with the permitted concentrations prescribed bythe EU Regulation 835/2011 (EC, 2011).

Finally after conducted research it can be concluded that the best results in terms of browning reduction, acceptable quality and sensory characteristic of MPP were achieved by applying 2% SA solution and packaged in VP up to the 8th day of storage with the 5th months old tubers. Further, cv. Birgit emerged as a better choice of cultivar for the MPP production. Nevertheless, the results obtained for 2% SC as well as cv. Lady Claire did not lag far behind. Cv. Lady Claire showe disadvantages in terms of reduced tendency to accumulate sugars during storage, lower content of acrylamide after frying and lower oil absorption during frying.

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Autobiography

Draženka Dite Hunjek is a production manager in Intersnack Adria d.o.o. (previous Adria Snack Company d.o.o.) since 2015. Prior to that position, she worked as a Quality Assurance analyst for Franck d.d. (2013-2015), she was a teacher in the School of Economics and Tourism in Daruvar (2012-2013) and product quality controller in the oil factory Gea-tvornicaulja d.o.o.In 2009, she became a Bachelor of Biotechnology at University of Zagreb, Faculty of Food Technology and Biotechnology with a thesis „The influence of different protectors on the survival of probiotic lactic acid bacteria during freeze-drying".In 2011 she graduated with a thesis „Functionality of the S-layer protein from the probiotic strain *Lactobacillus helveticus*M92" and became Master of Molecular Biotechnology at University of Zagreb, Faculty of Food Technology and Biotechnology. In 2012, she passed Pedagogical-Psychological-Didactic and Methodological Training at Faculty of Philosophy in Osijek. Currently, she is finishing Postgraduate University Doctoral Study „Biotechnology andBioprocess engineering, Food technology and Nutrition" atUniversity of Zagreb, Faculty of Food Technology and Biotechnology. The area of her research is the impact of minimal potato processing methods on the quality and health of products before and after heat treatment. She is an associate on the project of the Croatian Science Foundation, which funds the mentioned research. In 2011 she received the Dean's Award for Student Work „The potential of cabbage (*Brassica oleracea* var. capitata) in the phytoremediation of cadmium". She is a member of Croatian Society of Food technologists, Biotechnologists and Nutritionists (HDPBN).

List of publications

Original scientific papers

Dite Hunjek, D., Pelajić, Z., Čošić, Z., Pedisić, S., Repajić, M., Levaj, B. (2021) Chemical constituents of fresh-cut potato as affected by cultivar, age, storage and cooking. *J. Food Sci.***, 86(5)**, 1656-1671. doi: https://doi.org/10.1111/1750-3841.15712.

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