

DR. UROŠ NOVAK (Orcid ID : 0000-0003-0561-8427)

Article type : Original Manuscript

Active chitosan-chestnut extract films used for packaging and storage of fresh pasta

Kristi Kõrge^{1,2}, Marijan Bajić¹, Blaž Likozar¹, Uroš Novak¹

¹ Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Hajdrihova 19, 1000 Ljubljana, Slovenia

² Department of Chemistry and Biotechnology, Tallinn University of Technology, Akadeemia tee 15, 12618, Tallinn, Estonia

Summary

A tannins-rich chestnut extract was used to enhance the antioxidant and antibacterial properties of chitosan-based film materials. The favorable mechanical properties of the novel material enabled its application in the preparation of the sachets that were used for packing and storage of filled fresh pasta. The fresh pasta aging progressed in conventional refrigerated storage conditions of 8 °C with 60 ± 2% relative humidity in the absence of light for 60 days. The rapid moisture mobility between a starchy food and sachets during the first nine days of storage induced retrogradation of the fresh pasta, whereby total phenolic content show dependency on moisture throughout the shelf life. Active components within the sachet prevented microbial growth on the food surface during the entire 60 days.

Keywords: chestnut extract; chitosan-based film; active sachet; antibacterial and antioxidant activity; fresh pasta; shelf life

Corresponding author.

E-mail address: uros.novak@ki.si (U. Novak)

The peer review history for this article is available at <https://publons.com/publon/10.1111/ijfs.14569>

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/IJFS.14569

This article is protected by copyright. All rights reserved

Introduction

Active biodegradable materials have recently emerged as an alternative capable of replacing conventional fossil fuel based plastic packaging in the food industry (Rodríguez-Rojas *et al.*, 2019; Moustafa *et al.*, 2019; Sabbah *et al.*, 2019). In addition, antimicrobial properties of such materials can be enhanced by the incorporation of various antimicrobial agents. Providing slow but constant migration of the active agents from the packaging material is an advantage in favor of the control of microbial growth over a longer period of time (Jideani & Vogt, 2016; Quintavalla & Vicini, 2002; Sung *et al.*, 2013).

With global production of 14.3 million tons, pasta is one of the most consumed food products worldwide (International Pasta Organisation, 2017). Fresh pasta is classified as intermediate moisture food with moisture content (MC) of 35% and a reported shelf life 37-60 days (Del Nobile *et al.*, 2009; de Camargo Andrade-Molina *et al.*, 2013). Several studies rely on modified atmosphere to enhance shelf life of perishable foods packed in conventional (fossil fuel-based) plastic packaging (Körge & Laos, 2019; Sanguinetti *et al.*, 2011) but, notably, scarce literature covers packaging of fresh pasta into biopolymer-based sachets (de Camargo Andrade-Molina *et al.*, 2013). However, replacing this pliable and easily shaped material is quite challenging because novel biodegradable materials have high water-affinity and sometimes do not have sufficient mechanical properties or water vapor barrier capabilities. Therefore, mastering the structural modifications of the current biodegradable materials is an essential step for their practical use in everyday life.

Chitosan is a biocompatible, biodegradable, non-toxic, and partly deacetylated, derivative of chitin, whereby its characteristics highly depend on its degree of deacetylation and molecular weight (Borić *et al.*, 2018). Chitosan is also endowed with a good film-forming capacity (Chillo *et al.*, 2009), that makes it one of the most favorable biopolymers for the preparation of environmentally-friendly films intended for food packaging and protection (Divya *et al.*, 2018; Wang *et al.*, 2018). The inherent antioxidant and antimicrobial properties of chitosan-based films' can be significantly improved with the incorporation of various plant-based active components, and therefore help in the extension of the shelf life of perishable foods (Wang *et al.*, 2018; Priyadarshi *et al.*, 2018b). Among others, it has been shown that essential oils of citrus (Randazzo *et al.*, 2016), caraway (Hromiš *et al.*, 2015) and *Litsea cubeba* (Zheng

et al., 2018) as well as different extract like turmeric (Kalaycioğlu *et al.*, 2017), spirulina (Balti *et al.*, 2017), hop and oak (Bajić *et al.*, 2019b) can be used for this purpose. In this context, industrial tannin extracts obtained from the chestnut wood (*Castanea sativa*) have prominent antioxidant activity (Squillaci *et al.*, 2018; Molino *et al.*, 2019), and as such could be very interesting candidates as active components in chitosan-based films.

The aim of this study is to explore the possibility to use chestnut extract (CE) as an active component in chitosan-based film materials, which can be further implemented for the preparation of bio-based packaging. Specifically, the sachets prepared from chitosan-based films with incorporated CE were used for packing of fresh pasta and a comparative analysis was conducted to assess the sachet's influence on microbial growth, moisture mobility (in relation to total phenolic content), and microstructural alterations of packed material.

Materials and methods

Materials

High molecular weight chitosan (CH) (acetylation degree $\geq 75\%$, 310-375 kDa), lactic acid (LA) (purity $\geq 85\%$), gallic acid (GA), and Folin-Ciocalteu's phenol reagent were purchased from Sigma-Aldrich (Steinheim, Germany), while methanol and acetone were from Avantor Performance Materials (Gliwice, Poland) and Honeywell (Hannover, Germany), respectively. Sodium carbonate was obtained from Merck (Darmstadt, Germany), and glycerol (GLY) from Pharmachem Sušnik (Ljubljana, Slovenia). Commercially available CE ($\geq 75\%$ tannins; $< 4\%$ of ash) was provided by the company Tanin Sevnica (Sevnica, Slovenia). All chemicals except LA were of analytical grade. Milli-Q[®] water was used throughout all experiments.

Preparation and characterization of active film packaging

Preparation of film-forming solutions

Film-forming solutions (FFSs) were prepared according to a slightly modified protocol described in Bajić *et al.*, (2019a). In short, CH (1.5% w/v) and GLY (plasticizer; 30% w/w based on the mass of CH) were dissolved in an aqueous solution of LA (1.0% v/v). The mixture was agitated overnight on a

magnetic stirrer IKA[®] RCT (IKA, Staufen, Germany) at 1000 rpm and room temperature (24 °C) until homogenization, and then vacuum-filtered through two sheets of medical gauze. Afterwards, the mixtures were supplemented with 0.0% (reference sample), 0.5%, 1.0%, and 1.5% w/v of CE in order to study its effect on the active properties of film materials, homogenized (at 6000 rpm during 2 min) with Ultra-Turrax[®] T50 (IKA, Staufen, Germany), and left overnight. Finally, a formed sticky foam and remaining bubbles were carefully removed from the mixtures using a laboratory spatula, and the mixtures were used for the film preparation.

Preparation of chitosan-based film material

Prepared FFS was cast on rectangular polyurethane 12 cm × 12 cm Petri dishes (~0.32 mL of FFS per cm² of a Petri dish) and left to dry in a drying oven Kambič (Semič, Slovenia) with a continuous ventilation (24 °C, RH 40% for 48h) (Bajić *et al.*, 2019a). Obtained films (mean diameter 120 ± 2 μm; measured by ABS Digital Thickness Gauge, Mitutoyo, Aurora, USA) were peeled off from the Petri dishes, separated with baking paper to prevent direct contact from each other and stored in an air-tight container (24 °C, no exposure to light) prior the analysis.

Total phenolic content of chitosan-based film material

Total phenolic content (TPC) in chitosan-based film material was determined using Folin-Ciocalteu's (FC) phenol reagent, according to the protocol outlined in our previous study (Bajić *et al.*, 2019a). Briefly, small rectangular film samples were added in water (~5 mg of film per mL of water), followed by the successive addition of FC phenol reagent and aqueous solution of Na₂CO₃ (10% w/v) in the amount of 10 vol% and 20 vol% based on the volume of water, respectively. After the incubation of samples (2 h in dark, 24 °C) the absorbance was measured at 765 nm using Synergy™ 2 Multi-Detection Microplate Reader (BioTek, Winooski, USA). Gallic acid was used as the standard and the results were expressed as the mass of gallic acid equivalent (GAE) per mass of the films.

Radical scavenging activity of chitosan-based film material

Determination of the antioxidant activity of chitosan-based films was done using 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. The rectangular film samples were added in a freshly prepared 60 μM DPPH methanolic solution (~ 5 mg of film per mL of the solution) and incubated for 2 h in a dark place and room temperature. The absorbance for each methanolic extract was measured at 517 nm on Lambda 40 UV/Vis spectrophotometer (PerkinElmer, Waltham, USA). The inhibition activity (%I) of each sample was calculated as $\%I = ((A_{\text{control}} - A_{\text{sample}})/A_{\text{control}}) \times 100$ (Kaya *et al.*, 2018), where A_{control} and A_{sample} denote the absorbance of DPPH solution and the absorbance of solutions containing the films samples, respectively.

Antibacterial properties of chitosan-based film material

Antibacterial properties of chitosan-based films were tested against *Escherichia coli* K12 (*E. coli*) and *Bacillus subtilis* DSM 402 (*B. subtilis*). A fresh bacterial culture suspension in the exponential growth phase ($\text{OD}_{600} = 0.5$) was spread over the Luria-Bertani agar culture medium, and the UV light-sterilized (at 254 nm for 15 min; both sides) rectangular film samples ($\sim 1 \text{ cm}^2$) were placed on the plate surfaces and incubated (37 $^{\circ}\text{C}$, 24 h) (Bajić *et al.*, 2019a). Clear areas that appeared around the films were considered as the inhibition zones (I_z).

Optical properties of chitosan-based film material

Rectangular film samples were cut to fit the size of a cuvette and carefully placed in it using tweezers. The samples were always kept to the same wall of the cuvette to provide equal distance from the light source in each measurement. The absorbance (A) was recorded at room temperature using Lambda 40 UV/Vis spectrophotometer under the wavelengths region ranging from 250 nm to 800 nm, whereby an empty cuvette (i.e. air) was used as the referent. The opacity (O) was calculated as $O = A_{600} / \text{film thickness (mm)}$ (Sun *et al.*, 2017), while the percent of transmittance (%T) was calculated as $\%T = 10^{-A} \times 100$ (Bajić *et al.*, 2019a).

Preparation of sachets

Each sachet was prepared from two sheets of chitosan-based film material (prepared from the FFS containing 1% w/v of CE according to protocols explained in section Preparation and characterization of active film packaging) by heat sealing (165 °C, 700 Pa, 7 s) on HST-H6 heat seal tester PARAM® (LabThink, Jinan, China). The first set (sachet in contact with food) was used to pack fresh pasta and the other was heat-sealed without the pasta (reference sachet).

Preparation and packing of fresh pasta

Preparation of fresh pasta

Fresh pasta (from here onwards pasta) was provided by Mlinotest (Ajdovščina, Slovenia). In short, the production of pasta involves filling/dough preparation, shaping, pasteurization (98 °C), drying/cooling, and packaging. The pasta ingredients were as follows: wheat meals, eggs with the filling (cottage cheese and spinach) with nutritional values calculated on the label: carbohydrates 45% (sugars 1.4%), protein 11%, fat 5.1% (saturated fat 2.5%), dietary fibers 2.1%, and salt 0.7%. Material that was used to pack pasta is a combination of polyethylene (PE), biaxially oriented polypropylene (BOPP), and ethylene vinyl alcohol (EVOH) (thickness 70 µm).

Packing of fresh pasta

The factory-packed pasta in modified atmosphere (MAP) conditioned PE-BOPP-EVOH plastic packaging (reference pasta) was re-packed into chitosan-chestnut extract (CH-CE) sachets (8 pieces) and heat sealed from the open end. Received sachets were inserted into paper envelopes to prevent their contact with each other. The entire process was conducted under laminar flow hood conditions (constant ventilation, 24 °C, 40% RH, ultraviolet light) to prevent microbial contamination. Samples were stored in a refrigerator at 8 °C and RH of 60 ± 2% during 60 days.

Characterization of the CH-CE sachet-pasta system

All the samples (reference sachets, reference pasta, sachets with pasta – eventually analyzed as a separate sample, i.e. pasta and CH-CE sachet) were tested for water activity, moisture, *TPC*,

microbiology (pasta only), Fourier-transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM) at days 0, 3, 6, 9, 12, 30 and 60. Final CH-CE sachet-pasta systems were analysed in three biological replicas.

Water activity

LabMaster-aw neo (Novasina, Lachen, Germany) was applied to measure reference samples, pasta's and CH-CE sachets' water activity (a_w). After the packaging was removed from storage it was opened under ventilating laminar flow hood. A pasta piece was cut and immediately placed into a measuring cup to prevent moisture loss. For the film analysis, a sample was cut from the sachets' middle section.

Moisture content

Moisture analyzer HE 53 (Mettler Toledo, Wien, Austria) was used to measure the moisture content of reference samples, pasta and CH-CE sachets. Pasta samples were analyzed by receiving a pasta piece from cold storage, cut into smaller particles and immediately placed onto a measuring plate for analysis. Sachet samples were handled in a similar manner, using scissors for cutting.

Total phenolic content

Total phenolic content of sachets

A *TPC* of active sachets (~5 mg) are determined by Folin Ciocalteu's (FC) phenol reagent according to protocol as described in section Total phenolic content of chitosan-based film material.

Total phenolic content of fresh pasta

To measure *TPC* in pasta samples, extraction of phenols was done prior to analysis according to the protocol outlined in a study of Vignola *et al.*, (2018). The samples (200 mg) were pre-powdered in liquid nitrogen, weighted on an analytical balance (Kern, Balingen, Germany), and covered with 1 mL extraction solution of methanol:acetone:water (30:30:40 mL). The prepared mixture was agitated on Tehtnica Vibromix 10 (Domel, Železniki, Slovenia) vortex during 5 min and centrifuged (7000 rpm; 10 min) using MiniSpin centrifuge (Eppendorf, Hamburg, Germany). Green-colored supernatant was

Accepted Article

pipetted into separate e-tube and the extraction was repeated. After the double extraction process, supernatants were mixed, 20 μL of the sample (supernatant) added to 120 μL water, followed by successive addition of FC phenol reagent and Na_2CO_3 (10% w/v) aqueous solution 10% w/v and 20% w/v based on the volume of the sample, respectively. Received samples were diluted with water up to 1 mL. After the incubation of samples (2 h in dark, 24 $^\circ\text{C}$) the absorbance was measured at 765 nm using Synergy™ 2 Multi-Detection Microplate Reader (BioTek, Winooski, USA). Gallic acid was used as the standard and the results were expressed as the mass of gallic acid equivalent (GAE) per mass of the pasta.

Microbiological analysis of fresh pasta

For the microbiological analysis, 4 ± 0.5 g of pasta sample was aseptically transferred into a sterile plastic homogenizer bag and blended with 36 ± 4.5 mL of 0.1% (w/v) sterile buffer Peptone water (BPW) using Masticator Basic blender (IUL Instruments, Barcelona, Spain) for 30 s, 1500 rpm, and at 24 $^\circ\text{C}$. Thereon, dilutions were prepared with 0.1% BPW and 100 μL of each dilution was inoculated into plate count agar growth medium. Dichloran Rose Bengale Chloramphenicol Agar (Biokar diagnostics, Allonne, France) was used for a total count of yeast and molds, Tryptic Glucose Yeast agar was used for a total bacterial count determination and Violet Red Bile Lactose Agar (Merck KGaA, Darmstadt, Germany) was used for total count of bacterial group *Enterobacteriaceae*.

Scanning electron microscopy

Scanning electron microscopy SUPRA 35VP (Carl Zeiss, Jena, Germany) was used to visualize morphological changes of sachets and pasta dough cross-section during shelf life. All the samples were mounted on metal stubs with carbon tape and observed using a voltage of 1.00 kV and magnifications 1.00K, 500 for the sachet film and pasta, respectively.

Fourier-transform infrared spectroscopy

The Fourier-transform infrared spectra of prepared films and pasta were recorded at the wavenumbers ranging from 4000 cm^{-1} to 700 cm^{-1} and resolution of 4 cm^{-1} , using Spectrum Two FT-

IR spectrometer (PerkinElmer). The sample (cheese and film) specters were normalized before carrying out the statistical analysis by averaging each value of the spectrum values. Each sample was scanned in triplicate.

Statistical analysis

The data was subject to the one-way analysis of variance (ANOVA) with a confidence level of 95% ($p \leq 0.05$), followed by Tukey's test. All the results in triplicate are expressed as the mean \pm standard deviation.

Results and discussion

Preparation and characterization of active film packaging

The FFSs containing 0.0% (control sample), 0.1%, 0.5%, and 1.0% (blended samples) were successfully used for the preparation of chitosan-based film material. The prepared films were preliminary characterized regarding the effect of the incorporated extract on their active (antioxidant-, antibacterial-, and optical-related) properties (Table 1).

Table 1. The effect of the chestnut extract concentration on the properties of chitosan-based films

Film sample [*]	Antioxidant-related properties		Antibacterial-related properties		Optical-related properties	
	TPC [§] [mg _{GAE} g _{film} ⁻¹]	I [§] [%]	I _z (<i>E. coli</i>) [§] [mm]	I _z (<i>B. subtilis</i>) [§] [mm]	A ₃₅₀ [§] [%]	O [§] [mm ⁻¹]
CE_0.0	0.4 \pm 0.1 ^a	9.0 \pm 6.0 ^a	0.01 \pm 0.1 ^a	0.01 \pm 0.1 ^a	59.9 \pm 5.0 ^a	0.85 \pm 0.2 ^a
CE_0.1	3.4 \pm 0.2 ^b	35.3 \pm 11.0 ^b	2.50 \pm 0.5 ^a	1.90 \pm 1.0 ^a	5.50 \pm 1.0 ^b	1.53 \pm 0.3 ^a
CE_0.5	11.2 \pm 2.0 ^c	76.2 \pm 5.0 ^c	2.50 \pm 2.0 ^a	7.50 \pm 1.0 ^a	0.01 \pm 0.1 ^b	3.73 \pm 0.4 ^b
CE_1.0	18.7 \pm 3.0 ^d	81.8 \pm 3.0 ^c	17.8 \pm 2.0 ^b	15.5 \pm 5.0 ^b	0.01 \pm 0.1 ^b	5.71 \pm 0.4 ^c

^{*} Labels CE_0.0, CE_0.1, CE_0.5, CE_1.0 indicate chitosan-based films prepared from the FFSs containing 0.0% (control sample), 0.1%, 0.5%, and 1.0% (w/v) of CE, respectively.

[§] Different subscript letters in each separate column indicate the samples with significantly different mean values ($p < 0.05$).

The films exhibited favorable antioxidant properties, whereby the TPC values (up to 18.7 mg_{GAE} g_{film}⁻¹) were in a positive correlation with films' radical scavenging activities (up to 81.8%). Besides,

the incorporation of CE endowed the films by antibacterial activity against *E. coli* (I_z was up to 17.8 mm) and *B. subtilis* (I_z was up to 15.5 mm) (Figure 1).

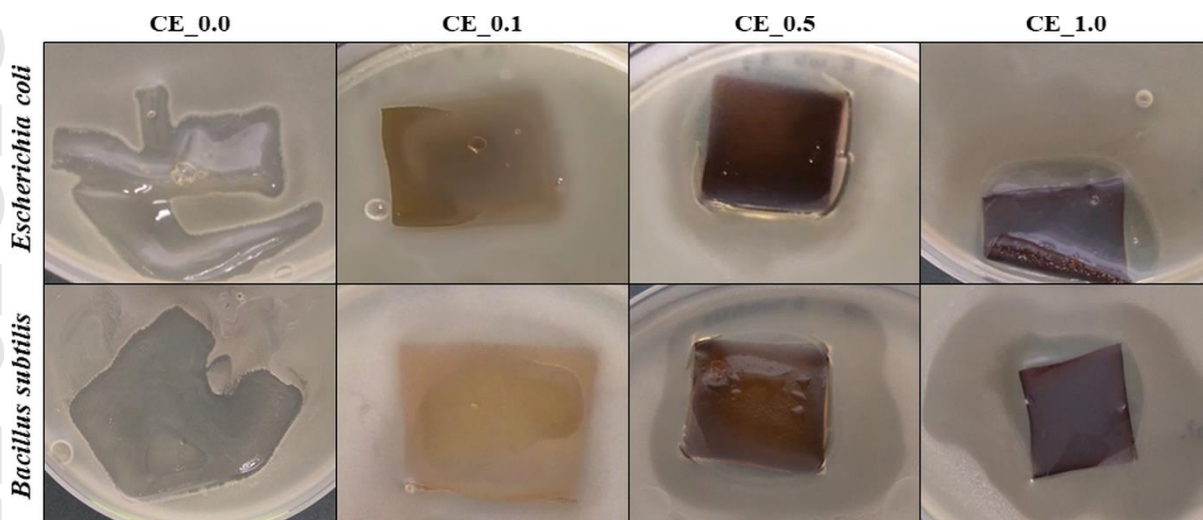


Figure 1. The appearance of inhibition zones visible around chitosan-based films after the incubation in a medium containing *E. coli* (upper row) and *B. subtilis* (lower row). Labels CE_0.0, CE_0.1, CE_0.5, CE_1.0 indicate chitosan-based films prepared from the FFSs containing 0.0% (control sample), 0.1%, 0.5%, and 1.0% (w/v) of CE, respectively.

Finally, evaluation of the films' optical properties has revealed that samples prepared from the FFSs containing CE had opacity values of up to 5.71 mm^{-1} (Table 1), while the percent of transmittance in the UV and visible wavelength range (from 250 nm to 800 nm) can be seen in Fig. 2.

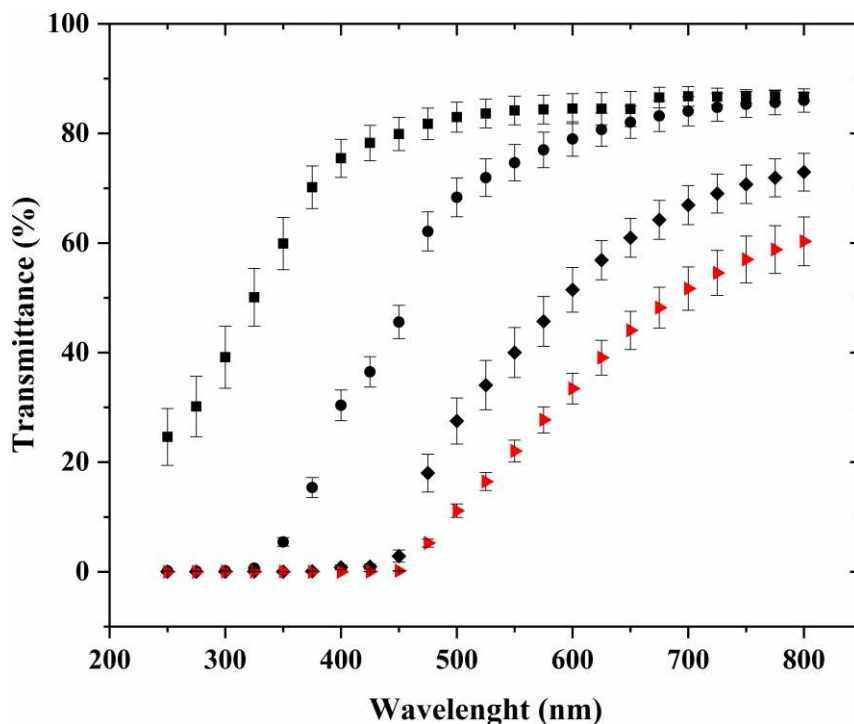


Figure 2. Optical properties of chitosan-based films of CE 0% (■), 0.1% (●), 0.5% (◆) and 1% (▸) in the UV-Vis wavelength range. Labels CE_0.0, CE_0.1, CE_0.5, CE_1.0 indicate chitosan-based films prepared from the FFSs containing 0.0% (control sample), 0.1%, 0.5%, and 1.0% (w/v) of CE, respectively.

The evaluated properties are important in providing sufficient protective capabilities of chitosan-based film materials. Besides, the trends of antioxidant-, antibacterial-, and optical-related properties observed after increasing the concentration of CE were in line with trends reported for other chitosan-based films blended with different types of plant-originating extracts (Bajić *et al.*, 2019b; Kaya *et al.*, 2018; Rambabu *et al.*, 2019; Priyadarshi *et al.*, 2018a; Sun *et al.*, 2017). Therefore, the incorporation of CE notably improved properties of chitosan-based films, making them appropriate for further use as active packaging materials, as discussed in the following chapters.

Characterization of the CH-CE sachet-pasta system during shelf life

Moisture mobility

Mobility of the moisture was evaluated under conventional refrigerated storage conditions at 8 °C with $60 \pm 2\%$ relative humidity in the absence of light for 60 days. Figure 3 depicts results of moisture desorption from pasta to CH-CE sachet and adsorption of the sachet *vice versa*. Reference pasta and reference sachet results are visualized for comparison.

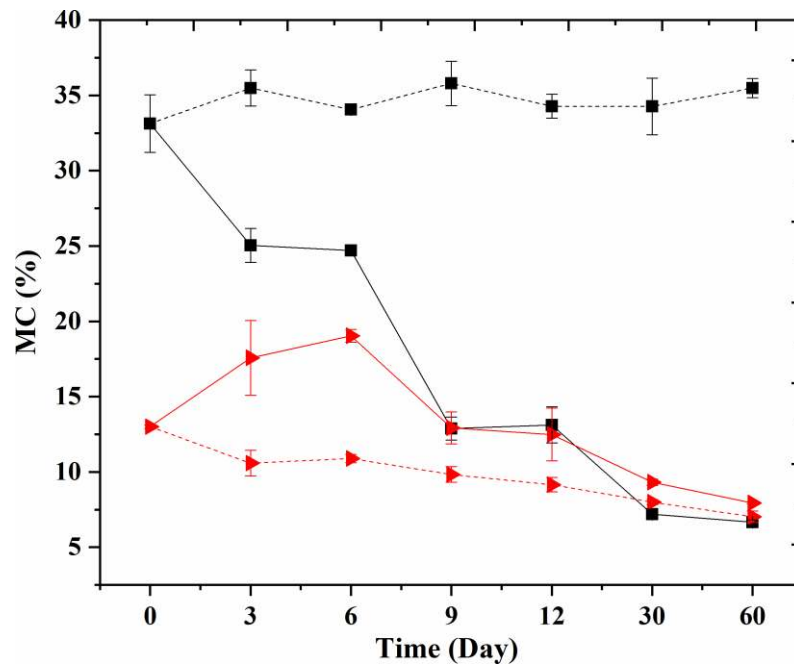


Figure 3. Moisture mobility of the pasta (■) and CH-CE sachet (►) during storage where dashed lines represent reference sample values.

According to the moisture mobility in CH-CE sachet-pasta system, pasta bestowed 9% of its moisture when sachet reached to its moisture equilibrium. From this point on, CH-CE sachet-pasta system depleted its capability to maintain the shelf life of pasta accordance to commercial expectations. A rapid MC desorption of pasta was observed during first three days (8%), slowing down over next three (1%) and then a strong decrease (19%) over the remaining time. Tested pasta MC results represented the described behaviour of Bressani (2014) where pasta, during its shelf life goes through three stages: (i) formation of natural crust, (ii) drying, (iii) stabilization. A retrogradation process took place. A similar outcome has been reported in other studies with a starchy food, in particular with bread

staling. Accordingly, moisture starts to move from a crumb to crust and does not move back from crust to crumb because of inability to form new hydrogen bonds in tightened structure (Kerch *et al.*, 2010).

At the same time, Figure 3 depicts that CH-CE sachet acted as expected regards to pasta changes. During the first three days 6% *MC* increase in CH-CE sachet was observed. In comparison, bread has been shown to lose 3% of moisture to carboxymethyl cellulose-chitosan sachet after three days, but unfortunately they do not show moisture intake of the sachet (Noshirvani *et al.*, 2017). This is attributed to two theories: (i) plastification properties of moisture, i.e. water from the food that relaxes the matrix of the sachet making absorption easier, (ii) due to CE that elevates solubility with its hydrophilic groups through interactions with water, also plasticizer (GLY) (Alves *et al.*, 2018; Sun *et al.*, 2018). The slowing down of moisture mobility during three to six days apprised that the turnover point of the sachet moisture intake was approaching. Pereda *et al.*, (2010) showed moisture equilibrium of the chitosan film at 20% with one day (25 °C, 75% RH). In our study, CH-CE sachet matrix reached its highest *MC* capacity of 19% (4 °C, 60% RH) on the sixth day when started to reveal properties that allowed easy water molecule passage. Subsequent to the turnover point, pasta *MC* drop gets steeper and reaches from 25% to 10% by the ninth day compared to CH-CE sachet that lost its *MC* with slower pace from 19% to 12%.

Total phenolic content relation to water activity

TPC of bio-based films has been established as a reliable indicator of antioxidant capacity. By observation of moisture mobility and its effect as an intrinsic factor on phenolic content change, its dependence on *MC* was noted in both matrices. Moisture loss highlighted the concentration of already existing phenolic content in pasta and at the same time dilution in CH-CE sachet. Figure 4 depicts a *TPC* relation to bound water while the retrogradation process was in progress.

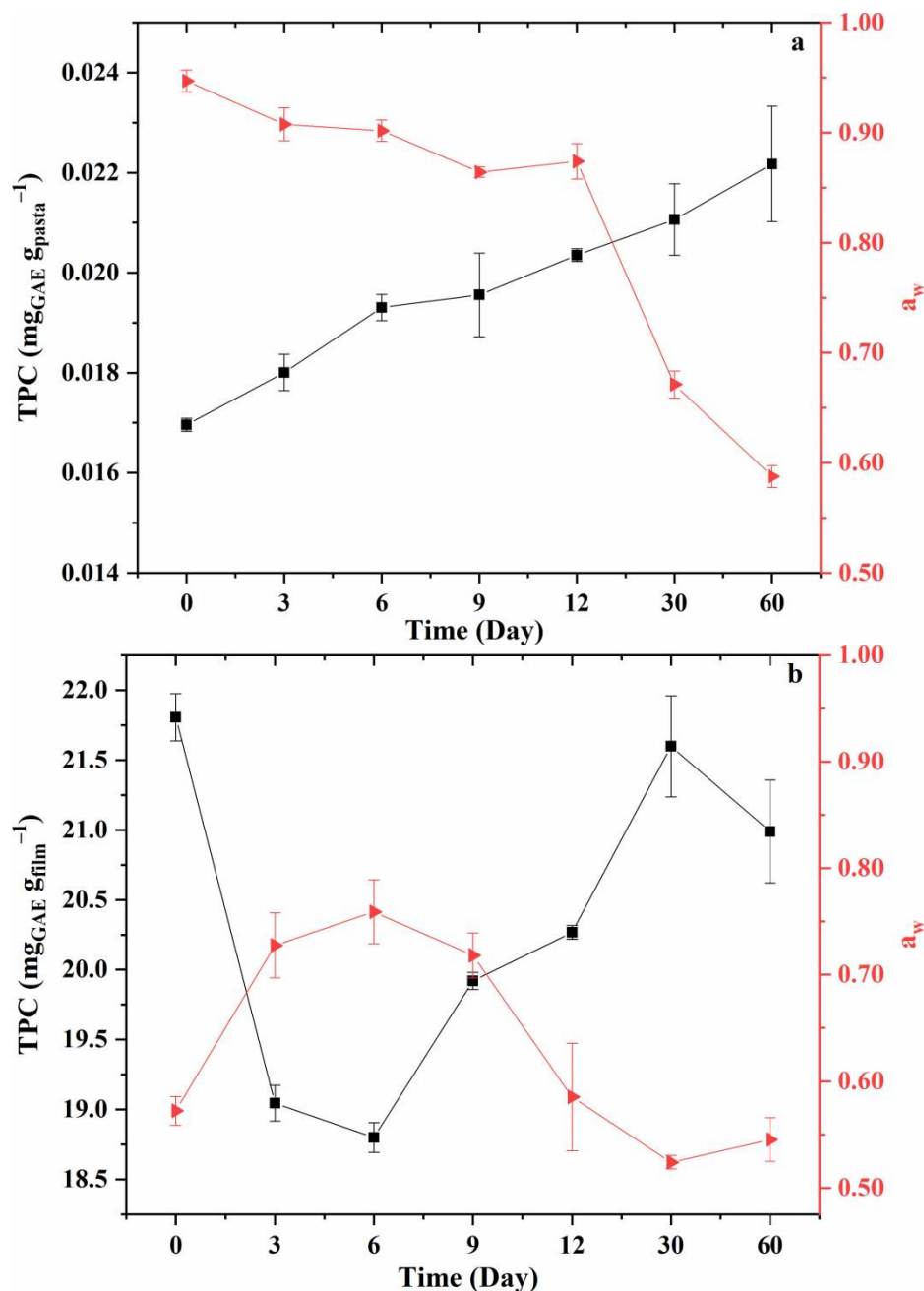


Figure 4. Total phenolic content and water activity changes of the a) pasta and b) CH-CE sachet in contact with one another during storage where the ■-marks represent TPC values and ►- water activity (a_w).

Phenolic content of pasta was measured $0.14 \text{ mg}_{\text{GAE}} \text{ g}_{\text{pasta}}^{-1}$ with a_w 0.950 and $0.18 \text{ mg}_{\text{GAE}} \text{ g}_{\text{pasta}}^{-1}$ with a_w 0.606 and MC 5.5% initially and after storage, respectively. Our results were in the range of $0.09 \text{ mg}_{\text{GAE}} \text{ g}_{\text{pasta}}^{-1}$ – $0.67 \text{ mg}_{\text{GAE}} \text{ g}_{\text{pasta}}^{-1}$ previously stated by Gull *et al.*, (2018) who worked with pasta that had 9% of moisture. Moreover, phenolic content in reference pasta (data not shown) remained stable ($0.14 \text{ mg}_{\text{GAE}} \text{ g}_{\text{pasta}}^{-1}$, average a_w 0.961) during the entire shelf life indicating, when a_w is stable

TPC is unchanged. In CH-CE sachets the TPC was measured $21.8 \text{ mg}_{\text{GAE}} \text{ g}_{\text{film}}^{-1}$ at the beginning of shelf life. A peculiar operation to marine biopolymer sachet, regards to a_w , describes decrease and after a while an increase of TPC near to initial value. This phenomenon indicates that there is likely no migration of phenolic content to the pasta surface.

Microbiology

The CH-CE sachet met the antimicrobial requirements and pasta, conditioned with $8 \text{ }^\circ\text{C}$, 60% RH, did not develop microbial growth during 60 days of storage. Total count of yeast, molds, bacteria and *Enterobacteriaceae* were all under detection limits (data not shown).

A short impact time (before retrogradation) for microbial activity was out ruled by a_w measurement in pasta. Figure 3 depicts that CH-CE sachet reaches a_w 0.730, making it a good surface for microbiology and if with heightened vapor permeability to an unprotective barrier against the hazard. But in opposite, even if a_w decrease in pasta was statistically significant accordance to a_w sorption isotherm graph (Roos *et al.*, 2018), it does not leave the range of moderate mold activity. In light of these results, it can be concluded that (under given conditions) antioxidant CH-CE sachet prevented microbial hazard and with high a_w .

Scanning electron microscopy

SEM images of pasta and CH-CE sachet cross-sections are shown in Figure 5 to assess their visible change during storage. The protein-starch matrix in the pasta samples is well formed throughout the shelf life with strong and continuous protein matrix entrapping uniform starch granules (Figure 5b). Focus on single starch granule showed that in the beginning of shelf life lenticular starch granules were slightly covered with amorphous network-type coating giving the indication of gelatinized starch via pasteurization during manufacture and presence of moisture (Sicignano *et al.*, 2015; Tudorica *et al.*, 2002). Although, the observation of amorphous coating was not seen in the end of the shelf life. Starch granules within the CH-CE sachet packed samples showed no signs of swelling and deformation (which could lead to additional gelatinization), indicating that they have been affected by moisture loss. Moreover, the protein-fiber matrix within reference pasta after 60 days appears to be have less tightened

than in the samples from CH-CE packaging, resulting distinguishable A and B-type granules (Sicignano *et al.*, 2015). SEM microphotos of different size granules and open spaces in between the matrix refer to more fresh-like texture of pasta.

The CH-CE sachet show a homogenous and evenly distributed structure on the third day when its moisture capacity was highest compared to the initial texture at day zero during shelf life (Figure 5a). When moisture is evaporating from CH-CE sachet it starts to show uneven cross-section, indicating weakened intermolecular interactions, as reported by Sogut & Seydim (2018). The CH-CE sachets did not develop any pores or visible thinning.

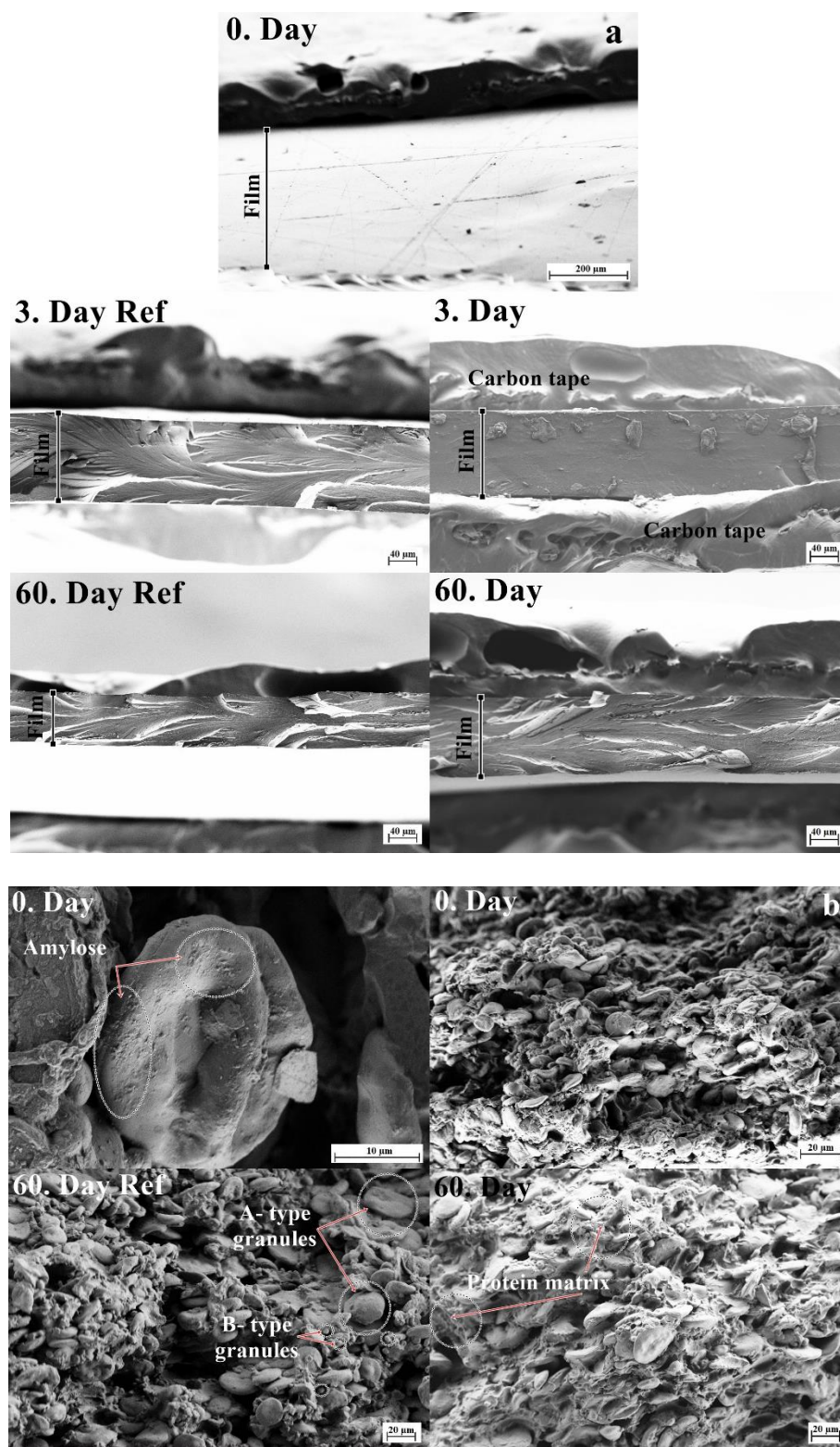


Figure 5. SEM images of a) CH-CE sachet and b) pasta on day 0, 3 and 60. From left to right pasta pictures visualize amylose amorphous phase covering single starch granule and cross-section structure on Day 0 and 60. Reference sample pictures are sided for comparison.

Fourier-transform infrared spectroscopy

It is known that the active packaging is capable of releasing its antioxidants or other macrocomponents onto food surface and *vice versa* (Noshirvani *et al.*, 2017; Sun *et al.*, 2018; Sogut & Seydim, 2018). Figure 6 describes FT-IR specters used to determine specific absorption bands of pasta and CH-CE sachet. In overall, peaks (Figure 6 a) on pasta spectra in the region 800 cm^{-1} to 1150 cm^{-1} refer to residual starch-protein interactions. The IR region from 1175 cm^{-1} to 1450 cm^{-1} provide information about sugars and organic acids. Presented are amide I band at 1650 cm^{-1} that results from C=O stretching and amidic band II from vibrations of N-H group with IR 1550 cm^{-1} . C-H band vibrations at 1700 cm^{-1} till 3000 cm^{-1} refer to ester carbonyl functional groups of the triglycerides. Peak-wise, our results incline with the results of Priyadarshi *et al.*, (2018a) and Durazzo *et al.*, (2018) groups. The analysed CH-CE sachets produced same characteristic absorption bands to pasta.

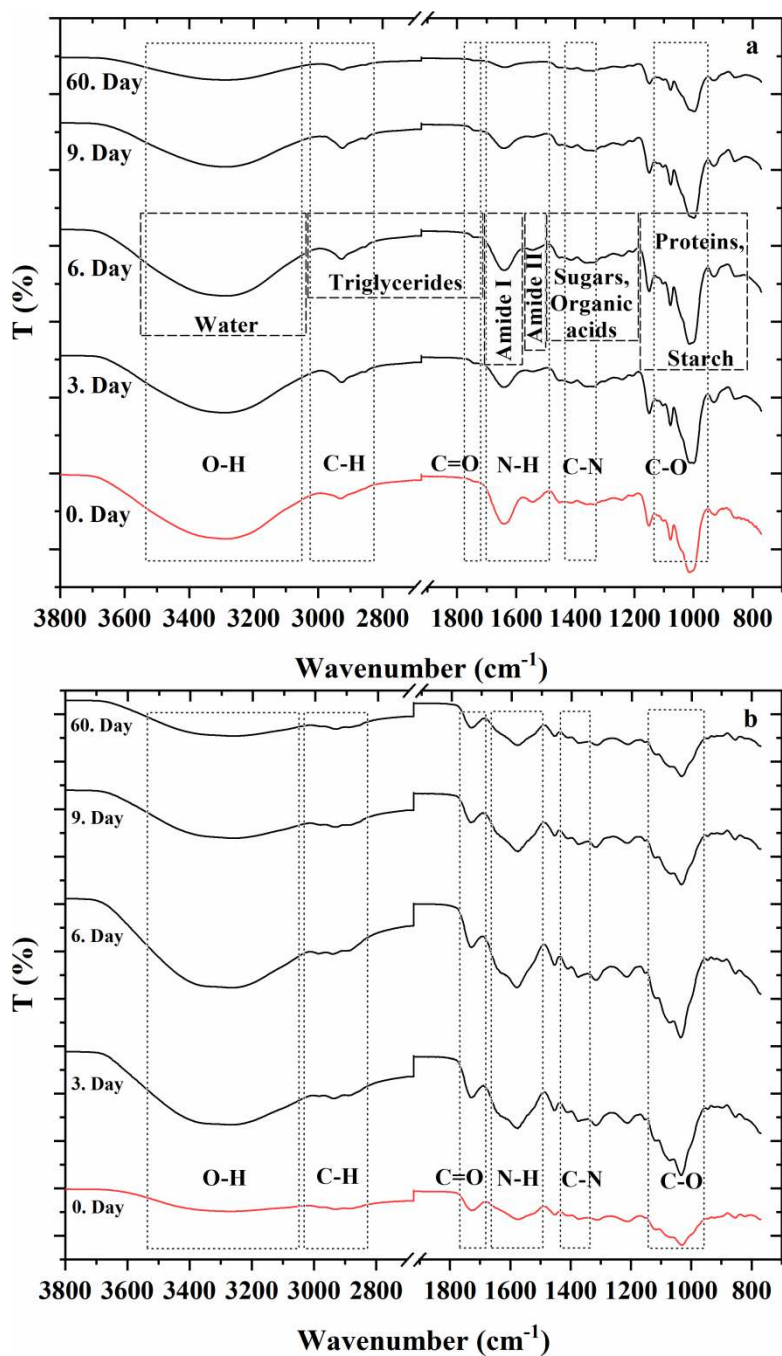


Figure 6. FT-IR results of the a) pasta and b) CH-CE sachet in contact during shelf life. Dashed boxes represent an approximate area of macrocomponents.

All the specters with CH-CE sachets showed O–H stretching vibrations in accordance with moisture mobility. Pasta, being more heterogeneous, received stronger O–H band intensity during the sixth day, but otherwise show a similar trend to *MC* results. No peak shifts or new peaks were detected on FT-IR specters generated for the reference pasta and sachet during shelf life. Changes were detected on

transmittance intensities. The IR regions of 800 cm⁻¹ to 1150 cm⁻¹ where residual starch is detected do not influence the same region on CH-CE sachet spectra. We could not differentiate CH-CE sachet components influence on pasta surface.

Conclusions

In this study, chitosan-based active film materials incorporated with CE were used to prepare sachets that were further used to pack fresh pasta. The antimicrobial activity of the film and its interactions within an active CH-CE sachet-pasta system during shelf life were evaluated during the shelf life. The results have shown that a retrogradation process of pasta has occurred, giving a hard-like texture after nine days of preservation in CH-CE sachet. Changes in a_w show total phenolic content concentration or dilution respectively to pasta and CH-CE sachet in contact. Regardless, pasta remained free of microbial spoilage in CH-CE sachet during the entire 60-day shelf life. According to FT-IR and SEM results, active packaging ingredients did not affect food surface and its microstructure. In spite of the antimicrobial properties, fresh pasta shelf life was not realized during the 60 days because of the unacceptable texture. Therefore, further research is required to improve the chitosan-based film permeability properties and/or to investigate alternative food products with a higher natural moisture barrier. Moreover, the possible coloring effect of the films (extracts) onto fresh pasta, which will require additional sensory analysis that relates directly to customers acceptance, was not part of our current studies. The sensory analysis studies will be investigated in the future.

Conflicts of interest

The authors declare no competing interests.

Acknowledgements

This work was facilitated with the financial support provided by the BioApp project (Interreg V-A Italy-Slovenia 2014-2020) and the Slovenian Research Agency (research core funding No. P2-0152). Authors wish to thank Brett Pomeroy and Ana Bjelić (National Institute of Chemistry, Ljubljana, Slovenia), Ana Velikonja (Mlinotest d.d.), and Helena Jalšovec (Acies Bio d.o.o., Ljubljana, Slovenia)

for their generous help during the experimental work. The companies Mlinotest and Tanin Sevnica are highly acknowledged for the donation of fresh pasta and chestnut extract, respectively.

Ethics approval was not required for this research.

Data availability statement

Research data are not shared.

References

Alves, V.L.C.D., Rico, B.P.M., Cruz, R.M.S., Vicente, A.A., Khmelinskii, I., & Vieira, M.C. (2018). Preparation and characterization of a chitosan film with grape seed extract-carvacrol microcapsules and its effect on the shelf-life of refrigerated Salmon (*Salmo salar*). *LWT - Food Science and Technology*, **89**, 525–534.

Bajić, M., Jalšovec, H., Travan, A., Novak, U., & Likozar, B. (2019a). Chitosan-based films with incorporated supercritical CO₂ hop extract: Structural, physicochemical, and antibacterial properties. *Carbohydrate Polymers*, **219**, 261–268.

Bajić, M., Ročnik, T., Oberlintner, A., Scognamiglio, F., Novak, U., & Likozar, B. (2019b). Natural plant extracts as active components in chitosan-based films: A comparative study. *Food Packaging and Shelf Life*, **21**, 100365.

Referred publications from Bajić et al. distributes the knowledge of our preliminary work in regards to characterization of the chitosan films with added extracts. Based on the expertise, the current research had the insight to choose packaging material and active components to carry out the experiments.

Balti, R., Mansour, M.B, Sayari, N. *et al.* (2017). Development and characterization of bioactive edible films from spider crab (*Maja crispata*) chitosan incorporated with Spirulina extract. *International Journal of Biological Macromolecules*, **105**, 1464–1472.

Borić, M., Puliyalil, H., Novak, U., & Likozar, B. (2018). An intensified atmospheric plasma-based process for the isolation of the chitin biopolymer from waste crustacean biomass. *Green Chemistry*, **20(6)**, 1199–1204.

Bressani, G.M. (2014). Shrinkage prediction during pasta dehydration. *Food Science Commons*.

Chillo, S., Suriano, N., Lamacchia, C., & Del Nobile, M.A. (2009). Effects of additives on the rheological and mechanical properties of non-conventional fresh handmade tagliatelle. *Journal of Cereal Science*, **49(2)**, 163–170.

de Camargo Andrade-Molina, T.P., Shirai, M.A., Eiras Grossmann, M.V., & Yamashita, F. (2013). Active biodegradable packaging for fresh pasta. *LWT - Food Science and Technology*, **54(1)**, 25–29.

The publication is one of the few that was focusing on the similar experimental design we were conducting. Article had a strong input how to understand active biodegradable packaging effect for fresh pasta.

Del Nobile, M.A., Di Benedetto, N., Suriano, N., Conte, A., Corbo, M.R., & Sinigaglia, M. (2009). Combined effects of chitosan and MAP to improve the microbial quality of amaranth homemade fresh pasta. *Food Microbiology*, **26(6)**, 587–591.

Divya, K., Smitha, V., & Jisha, M.S. (2018). Antifungal, antioxidant and cytotoxic activities of chitosan nanoparticles and its use as an edible coating on vegetables. *International Journal of Biological Macromolecules*, **114**, 572–577.

Durazzo, A., Kiefer, J., Lucarini, M. *et al.* (2018). Qualitative analysis of traditional Italian dishes: FTIR approach. *Sustainability (Switzerland)*, **10(11)**.

Gull, A., Prasad, K., & Kumar, P. (2018). Nutritional, antioxidant, microstructural and pasting properties of functional pasta. *Journal of the Saudi Society of Agricultural Sciences*, **17(2)**, 147–153.

Hromiš, N.M., Lazić, V.L., Markov, S.L. *et al.* (2015). Optimization of chitosan biofilm properties by addition of caraway essential oil and beeswax. *Journal of Food Engineering*, **158**, 86–93.

International Pasta Organisation (2017). The world Pasta industry report. (2014). [http://www.internationalpasta.org/resources/World Pasta Industry Survey/IPOstatreport2014low.pdf](http://www.internationalpasta.org/resources/World%20Pasta%20Industry%20Survey/IPOstatreport2014low.pdf).

Jideani, V.A., & Vogt, K. (2016). Antimicrobial packaging for extending the shelf life of bread – A review. *Critical Reviews in Food Science and Nutrition*, **56(8)**, 1313–1324.

Kalaycıoğlu, Z., Torlak, E., Akın-Evingür, G., Özen, İ., & Erim, F.B. (2017). Antimicrobial and physical properties of chitosan films incorporated with turmeric extract. *International Journal of Biological Macromolecules*, **101**, 882–888.

Kaya, M., Ravikumar, P., Ilk, S. *et al.* (2018). Production and characterization of chitosan based edible films from *Berberis crataegina*'s fruit extract and seed oil. *Innovative Food Science and Emerging Technologies*, **45**, 287–297.

Kerch, G., Zicans, J., & Meri, R.M. (2010). The effect of chitosan oligosaccharides on bread staling. *Journal of Cereal Science*, **52(3)**, 491–495.

Körge, K., & Laos, K. (2019). The influence of different packaging materials and atmospheric conditions on the properties of pork rinds. *Journal of Applied Packaging Research*, **11(3)**.

Molino S., Casanova N.A., Henares J.A.R., & Fernandez Miyakawa M.E. (2019). Natural tannin wood extracts as a potential ingredient in the food industry. *Journal of Agriculture and Food Chemistry*. DOI: 10.1021/acs.jafc.9b00590

Referred article describes active components, which are also preset in the chestnut extract, that was used in our research. We found this article to be of great value to our article being thorough with its content.

Moustafa, H., Youssef, A.M., Darwish, N.A., & Abou-Kandil, A.I. (2019). Eco-friendly polymer composites for green packaging: Future vision and challenges. *Composites Part B: Engineering*, **172**, 16–25.

Noshirvani, N., Ghanbarzadeh, B., Rezaei Mokarram, R., & Hashemi, M. (2017). Novel active packaging based on carboxymethyl cellulose-chitosan-ZnO NPs nanocomposite for increasing the shelf life of bread. *Food Packaging and Shelf Life*, **11**, 106–114.

Pereda, M., Aranguren, M.I., & Marcovich, N.E. (2010). Water vapor absorption and permeability of films based on chitosan and sodium caseinate. *Journal of Applied Polymer Science*, **116(5)**, 2658–2667.

Priyadarshi, R., Sauraj, Kumar, B., Deeba, F., Kulshreshtha, A., & Negi, Y.S. (2018a). Chitosan films incorporated with Apricot (*Prunus armeniaca*) kernel essential oil as active food packaging material. *Food Hydrocolloids*, **85**, 158–166.

Priyadarshi, R., Sauraj, Kumar, B., & Negi, Y.S. (2018b). Chitosan film incorporated with citric acid and glycerol as an active packaging material for extension of green chilli shelf life. *Carbohydrate Polymers*, **195**, 329–338.

Publications by Priyadarshi R. et al. supported our research with the knowledge how chitosan film with certain plant extract benefits to high moisture food shelf life. Their work aligns with our work stating that increase of plant extract (in our case chestnut extract) in films increases antibacterial properties. Priyadarshi R. et al. (2018a) depict comparable FTIR results.

Quintavalla, S., & Vicini, L. (2002). Antimicrobial food packaging in meat industry. *Meat Science*, **62(3)**, 373–380.

Rambabu, K., Bharath, G., Banat, F., Show, P.L., & Cocolletzi, H.H. (2019). Mango leaf extract incorporated chitosan antioxidant film for active food packaging. *International Journal of Biological Macromolecules*, **126**, 1234–1243.

Randazzo, W., Jiménez-Belenguer, A., Settanni, L. *et al.* (2016). Antilisterial effect of citrus essential oils and their performance inedible film formulations. *Food Control*, **59**, 750–758.

Rodríguez-Rojas, A., Arango Ospina, A., Rodríguez-Vélez, P., & Arana-Florez, R. (2019). ¿What is the new about food packaging material? A bibliometric review during 1996–2016. *Trends in Food Science and Technology*, **85**, 252–261.

Roos Y.H., Finlay J.W. & deMan J.M. (2018). Water Activity and Food Spoilage. In J.M. deMan, J.W. Finlay, W.J. Hurst, & C.Y. Lee (Eds.), *Principles of Food Chemistry* (pp. 31). Maryland: Gaithersbury Inc.

Sabbah, M., Di Pierro, P., Dell’Olmo, E., Arciello, A., & Porta, R. (2019). Improved shelf life of Nabulsi cheese wrapped with hydrocolloid films. *Food Hydrocolloids*, **96**, 29–35.

Sanguinetti, A.M., Del Caro, A., Mangia, N.P., Secchi, N., Catzeddu, P., & Piga, A. (2011). Quality changes of fresh filled pasta during storage: Influence of modified atmosphere packaging on microbial growth and sensory properties. *Food Science and Technology International*, **17**(1), 23–29.

Sicignano, A., Di Monaco, R., Masi, P., & Cavella, S. (2015). From raw material to dish: Pasta quality step by step. *Journal of the Science of Food and Agriculture*, **95**, 2579–2587.

Sogut, E., & Seydim, A. C. (2018). The effects of chitosan and grape seed extract-based edible films on the quality of vacuum packaged chicken breast fillets. *Food Packaging and Shelf Life*, **18**, 13–20.

Squillaci, G., Apone, F., Sena, L.M. *et al.* (2018). Chestnut (*Castanea sativa* Mill.) industrial wastes as a valued bioresource for the production of active ingredients. *Process Biochemistry*, **64**, 228–236.

Sun, L., Sun, J., Chen, L., Niu, P., Yang, X., & Guo, Y. (2017). Preparation and characterization of chitosan film incorporated with thinned young apple polyphenols as an active packaging material. *Carbohydrate Polymers*, **163**, 81–91.

Sun, L., Sun, J., Liu, D., Fu, M., Yang, X., & Guo, Y. (2018). The preservative effects of chitosan film incorporated with thinned young apple polyphenols on the quality of grass carp (*Ctenopharyngodon idellus*) fillets during cold storage: Correlation between the preservative effects and the active properties of the active properties of the film. *Food Packaging and Shelf Life*, **17**, 1–10.

Sung, S.Y., Sin, L.T., Tee, T.T. *et al.* (2013). Antimicrobial agents for food packaging applications. *Trends in Food Science and Technology*, **33**(2), 110–123.

Tudorică C.M., Kuri V., & Brennan C.S. (2002). Nutritional and Physicochemical Characteristics of Dietary Fiber Enriched Pasta. *Journal of Agriculture and Food Chemistry*, **50**, 2, 347–356.

Vignola, M.B., Bustos, M.C., & Pérez, G.T. (2018). Comparison of quality attributes of refined and whole wheat extruded pasta. *LWT - Food Science and Technology*, **89**, 329–335.

Wang, H., Qian, J., & Ding, F. (2018). Emerging Chitosan-Based Films for Food Packaging Applications. *Journal of Agricultural and Food Chemistry*, **66**(2), 395–413.

Zheng, K., Li, W., Fu, B. *et al.* (2018). Physical, antibacterial and antioxidant properties of chitosan films containing hardleaf oatchestnut starch and *Litsea cubeba* oil. *International Journal of Biological Macromolecules*, **118**, 707–715.