A simple, efficient and economic method for obtaining iodate-rich chili pepper based chitosan edible thin film

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Abstract The present study was aimed at designing an iodine supplement in form of edible film made of iodate-coated chitosan (CS-IO₃). Inclusion of so obtained films in diet can help in preventing thyroid cancer, leading to improved public health. Chili pepper was coated with iodate thin film (1.5 µm). The iodate-rich film is ready-to-eat serving valuable nutrients. Stability studies of CS-IO₃ film using water dipping revealed that there was no leaching of iodate ion, due to the strong interactions between cationic amino group of chitosan and iodate ion. The film showed no change in its antioxidant activity. Iodate concentration in the film was determined at 620 nm selectively, based on the decolorization of malachite green economic method. Iodate content in fruits coated with 1.5% (w/v) CS-IO₃ was 11.5 mg g⁻¹ of dry film sample. The iodate-rich samples could be stored without much effect on its freshness, indicating a good shelf life.

Keywords Chili pepper · Chitosan · Iodate · Thin film · Freshness · Shelf life

Introduction

Iodine is an essential micronutrient trace element crucial for the proper functioning of the thyroid glands, and required for the synthesis of thyroid hormones (thyroxine and tri-iodothyronine) (Judprasong et al. 2016). In case of iodine deficiency, thyroid gland is not able to synthesize these hormones in sufficient quantities. The lack of sufficient iodine may thus lead to iodine deficiency disorders (IDDs) (Ajith et al. 2015). The most well-known of IDDs is “goiter” that involves enlargement of the thyroid gland. Another important IDD, albeit rare in occurrence is thyroid cancer (Leufroy et al. 2015). This causes a serious public health threat affecting over 260 million people worldwide (Yang et al. 2007). Therefore, it is necessary to obtain sufficient amount of iodine from different food.

Natural sources of iodine do not satisfy the requirements of body as the iodine from these sources is not in bio-available form and is present in low concentrations (Longvah et al. 2012). Adequate intake of iodine can be achieved by consumption of iodized salt. Potassium iodate (KIO₃) is normally used for salt fortification owing to its higher iodine availability and lower cost. Some of the other important advantages that potassium iodate offers are good levels of iodine, better bioavailability and relatively high stability even when stored under warm and humid conditions (Rebary et al. 2010). According to the World Health Organization (2007) to avoid iodine deficiency and its associated disorders, daily consumption of iodine must be approximately 180–200 µg day⁻¹. However, foods like iodized salts that contain iodine, have sodium chloride (NaCl) as the major component (Ranganathan et al. 2015). Its salty taste prohibits its consumption in large quantities and on a daily basis. Thus addition of iodine to salt alone is not able to eliminate the problem of iodine deficiency, as

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salt is not the main ingredient of daily diet. Additionally, cooking and food preparation practices lead to about 20% loss of iodine. Thus, in view of all the aforementioned facts, addition of iodine as a supplement to other foods and drinks such as drinking water, milk or even bread can be explored as an alternative option to address the problem of iodine deficiency (Longvah et al. 2013).

In this context, the edible coatings have been traditionally used to modify food products. Such edible coatings help preserve quality and they are also considered environmentally friendly. Films from plant materials have already been reported to have potential uses. Singh et al. (2009a) studied the effect of iodine on the properties of zein films and precipitates with a view to evaluating the system as a possible antimicrobial wound dressing. They also evaluated the effect of iodine on the structural characteristics (by infrared spectroscopy and X-ray) of films made from kidney bean starch (Singh et al. 2009b).

Chitosan (β -(1-4)-2-amino-2-deoxy-D-glucopyranose) is industrially produced by chemical deacetylation of chitin found in arthropod exoskeletons (da Silva Santos et al. 2017). Chitosan biopolymer has several unique properties which make it a suitable candidate for film-coating related applications. These properties include biodegradability, non-toxicity and edibility. In addition, it is also known to act as a good barrier to exterior elements (Guohua et al. 2016). Owing to all these properties, it can be used as an edible surface coating, thereby extending the shelf-life of fruits and vegetables. Another reason for the extensive use of chitosan derivatives is the presence of positively charged nitrogen atoms and the prominent active amino groups making it structurally suitable for coating of a variety of food products. A review of recently published literature shows that a lot of efforts have been dedicated to adding supplementary nutrients to food products by using edible coatings such as chitosan incorporated with montmorillonite and pomegranate rind powder extract (Qin et al. 2015), chitosan films incorporated with lauric arginate, cinnamon oil and ethylenediaminetetraacetate (Ma et al. 2016), iodide-chitosan coated tomato (Limchoowong et al. 2016), chitosan treatment on strawberry (Petriccione et al. 2017), chitosan-gallic acid and chitosan-gallate coated banana (Awad et al. 2017) and chitosan-ascorbic acid coated pomegranate arils (Özdemir and Gökmen 2017). One of the substrates of interest is chili pepper fruit, which is well-known for its nutritional and medicinal value and thus is in great demand in international trade (Yamaguchi et al. 2010). It is well known that chili peppers are a rich source of a number of vitamins including vitamins C, E and provitamin A. They are also known to be a good source of other antioxidants (Shahidi and Ambigaipalan 2015; Sandoval-Castro et al. 2017). Due to a high global demand, it is being produced on a large scale. In 2012, it was produced

over an area of about 3.9 million ha resulting in 34.5 million tons of harvested product (Naccarato et al. 2016).

To the best of our knowledge, there is no report dealing with the use of chitosan functionalized with iodate coating as a nutritive supplement for chili pepper fruit. The demand seems to be growing with every passing day, both in local as well as international markets. At the same time, a study of markets and consumer habits indicates that the demand is on rise for ready-to-eat foods with supplementary nutrients because of their appealing features such as convenience and nutritive value. We herein report the evaluation of CS-IO₃ based edible thin film as a novel alternative coating for foodstuffs. An ultrasound-assisted extraction was used for pretreatment of samples and iodate content in the CS-IO₃ film was determined by malachite green based absorption spectrophotometry.

Materials and methods

Chemicals and reagents

All chemicals and solvents used were of analytical reagent grade and all solutions were prepared in deionized water (Milli Q Millipore 18.2 M Ω cm⁻¹ of resistivity) from Millipore Corporation (USA). Shrimp shell chitosan (> 75% degree of deacetylation) 2,2-Diphenyl-1-picrylhydrazyl (DPPH), catechin and malachite green (MG) were purchased from Sigma-Aldrich (Japan). Glacial acetic acid, sulfuric acid, potassium iodide, sodium acetate, sodium carbonate and potassium iodate were purchased from QRecTM (New Zealand). Folin–Ciocalteu reagent was obtained from Merck (USA). The MG solution was prepared in deionized water at a concentration of 36.5 mg L⁻¹ and diluted to the mark in a 50 mL volumetric flask with deionized water.

Fruit material

Chili peppers (genus *Capsicum*) were purchased from local fresh market in Khon Kaen, Thailand. A total of 105 chili peppers were selected on the basis of certain criteria like uniformity of size (2.48 ± 0.32 g per fruit), presence of red pericarp, absence of physical damage and fungal infection. They were divided into two groups; one coated with pure chitosan and the other with CS-IO₃. Effects of treatment were checked once in a week. The effects were estimated by evaluating the samples on following parameters: weight loss, texture of the fruit, antioxidant activity and total phenolic compounds.

Edible film formulation

Chitosan solution was prepared by dissolving of 0.5 or 1.5 g chitosan powder in 100 mL of 1% (v/v) acetic acid followed by homogenization on a magnetic stirrer for 30 min. The mixtures were treated overnight at room temperature to remove air bubbles. The resultant chitosan solution was filtered in order to remove any undissolved particles. After filtration, film was cast by pouring the solution onto Petri dishes and drying it under ambient conditions until a thin film formed. The films were peeled off from the dishes for analysis. All experiments were done in triplicate.

Chitosan-iodate solution was prepared by dissolving the chitosan powder in 100 mL of 1% (v/v) acetic acid with continuous stirring. Subsequently, potassium iodate (KIO_3) was added (100 mg L^{-1}) with continuous stirring. The resultant solution was decanted into a Petri dish and left to dry under ambient conditions to yield the iodate coated chitosan film (CS- IO_3).

Iodate-rich chili pepper based chitosan coating

Chili pepper fruits were randomly distributed into five groups. Four groups were used for treatment with CS-iodate and CS solution to study film-coating, while the remaining one was meant to be the untreated as control group. Each of the treatments consisted of immersing fruits in the solutions of varying concentrations (about 1 min) as follows: (a) 0.5% CS; (b) 0.5% CS- IO_3 ; (c) 1.5% CS; and (d) 1.5% CS- IO_3 . After being dipped in each of solutions again, the fruits were allowed to air-dry and were placed on a tray at ambient temperature. For analysis, 75 fruits from each group were used and the experiment was performed in triplicate. Data were consecutively recorded over a period of next 4 weeks.

Ultrasonic-assisted extraction

An ultrasound-assisted extraction (UAE) is known to allow the release of target analytes in a short period of time due to its operation conditions involving atmospheric pressure and room temperature (Sricharoen et al. 2017a). Thus, UAE was selected for iodate extraction. At first, the iodate-chitosan composite (0.3 mL of solution and 0.0050 g of film) was accurately weighed and extracted with deionized water by ultrasonication for 5 min at 35 kHz (Sonorex Digitec DT 510 H, Bandelin, Germany) to leach out the target analyte (Limchoowong et al. 2017). After sonication, the obtained extract was separated from the remaining solid materials using centrifugation at 5000 rpm for 5 min. Three replicates of each alternative sample and blank were

used to optimize the analytical parameters of the extraction method.

Analytical procedures

Iodate concentration was determined by spectrophotometric method based on decolorization of malachite green (MG) solution (Konkayan et al. 2016). A 1 mL of standard solution or the sample extract was mixed with 40 mg L^{-1} iodide solution and 1 mL of 2 mol L^{-1} sulfuric acid, and then the reaction mixture was gently shaken until the appearance of yellow color. Thereafter, 1.4 mL of 36.5 mg L^{-1} malachite green was added, followed by addition of 2 mL of 2 mol L^{-1} sodium acetate and dilution to 10 mL with deionized water. After about 5 min, the absorbance of the reaction solution was recorded at 620 nm.

Physical property of the iodate coated chitosan film

Water solubility of the film sample

The iodate (100 mg L^{-1}) and chitosan solutions in a weakly acidic medium were mixed together with stirring for 30 min and stood at an ambient temperature for 24 h, for the removal of air bubbles. Then, it was uniformly poured onto a plastic sheet. The mixture was dried at room temperature until the film was formed and then the resultant film was peeled off for analysis. The dried iodate coated films (0.3 mL) were immersed in 5 mL distilled water at 25°C for 0.5, 1, 5, 10 and 30 min respectively. Then, the iodate content in this water extract was determined spectrophotometrically at 620 nm as mentioned above. Following a careful separation of the insoluble film, the separated film samples were dried at room temperature. The iodate extraction of the dried iodate coated film was also conducted in 5 mL deionized water with UAE for 5 min. The iodate extract was also determined. All the experiments were conducted in triplicate.

Weight loss determination of chili pepper

All samples of chili pepper obtained from each treatment were accurately weighed using an analytical balance (Sartorius, Germany) at the beginning of the experiment, just after coating and air-drying. These samples were stored at room temperature for a time span of 4 weeks and taken out for weighing on a weekly basis. The result was calculated and expressed in terms of percentage weight loss according to the following Eq. (1):

$$\text{WL}\% = [(W_i - W_f)/W_i] \times 100 \quad (1)$$

where, WL% is the percentage of weight loss, W_i is the initial weight of sample in gram, and W_f is the final weight of sample in gram at the indicated time.

Stability of the iodate-chitosan solution and the thin film

Stability studies were also carried out on the iodate containing chitosan films. The chitosan film required for this purpose was prepared as follows. Chitosan powder (0.5 or 1.5 g) was dissolved in 100 mL of acetic acid with stirring at room temperature. Potassium iodate (100 mg L^{-1}) was then added and stirred homogeneously. To obtain a film, the homogenous chitosan solution was poured onto a Petri dish and was left to dry. Subsequently, the iodate doped chitosan solution and its film were evaluated based on decolorization absorption of MG at 620 nm. The results were collected over a period of 4 weeks at ambient temperature.

Antioxidant activity by DPPH[•] radical scavenging assay and determination of total phenolic compounds

The free radical scavenging activity of the chili pepper was estimated based on its scavenging activity against the stable 2,2-diphenyl-1-picrylhydrazyl (DPPH[•]) free radical. The antioxidant activity of the extract was evaluated using DPPH radical assay (Sricharoen et al. 2017b). A 100 μL aliquot of the standard solution or the centrifuged extract was mixed with 900 μL of a 0.1 mM DPPH in ethanol. While ethanol was used as a control, the DPPH solution was used as a blank. The mixture was vigorously shaken, homogenized and kept for 30 min in the dark. All measurements were done under dim light. The absorbance was measured at 517 nm. For each sample, three independent measurements were carried out. The lower absorbance level of the reaction mixture indicated higher free radical scavenging activity. The DPPH[•] scavenging activity was calculated using the following Eq. (2):

$$\text{DPPH}\% = [(A_{\text{control}} - A_{\text{sample}})/A_{\text{control}}] \times 100 \quad (2)$$

where, A_{control} is the absorbance of the control reaction which contains all other reagents except, either the standard or the sample, and A_{sample} is the absorbance in the presence of the standard or the sample.

The total phenolic content of both, the extract and the antioxidant standard, was determined by Folin–Ciocalteu assay using (+)-catechin as a standard reference (Sricharoen et al. 2015). A 100 μL aliquot of the sample extract or the standard solution of (+)-catechin ($20\text{--}50 \text{ mg L}^{-1}$) was mixed with 500 μL of 10% Folin–Ciocalteu reagent. After

3 min, 400 μL of Na_2CO_3 (7.5% w/v) was added and the mixture was incubated in the dark at room temperature for 30 min. The absorbance against the reagent blank was measured spectrophotometrically at 765 nm. The total polyphenol content was expressed as milligram of (+)-catechin equivalent per gram of dry weight (mg CTE/g DW).

Results and discussion

Morphology and thickness of the chitosan film

Morphology and thickness of chitosan films were observed under a scanning electron microscope (SEM) (Hitachi S-3000 N, Japan). Figure 1a, b presents surface morphology of the chitosan films with and without potassium iodate, respectively. All chitosan films were clear and exhibited a smooth surface without any solid phase impurities. This confirms that the iodate was homogeneously distributed throughout the chitosan films. The surface of the iodate coated chitosan film was also found to be relatively smooth without any barrier. It can thus be used for coating the sample surface without any visually noticeable unevenness. Film thickness measurement (micrometer) studies were carried out on six films per ratio treatment and an average of measurements at five different points for each film was recorded using SEM imaging, as shown in Fig. 1c. The average thickness of the films was about 1.5 μm . Thickness measurement studies were carried out on both, pure CS films and CS films containing iodate.

FTIR spectroscopy

FT-IR spectrum (Tensor 27, Bruker Optics, Germany) of the sample was also recorded analyze the phase structure and the interaction between chitosan and iodate. Figure 1d shows the FT-IR spectra of chitosan and iodate-rich chitosan films in the range of $600\text{--}4000 \text{ cm}^{-1}$. The transmission infrared spectrum of chitosan displayed the C=O stretching (amide I) band near 1639 cm^{-1} and NH bending ($-\text{NH}_2$, amide II) band at 1547 cm^{-1} (Singh et al. 2009a; Pereira et al. 2015). The absorption band at 1404 cm^{-1} corresponds to the $-\text{CH}$ deformation. Other prominent bands that were observed were, 1379 cm^{-1} ($-\text{CH}$ symmetric deformation), 1322 cm^{-1} ($-\text{CH}$ wagging coupled with in-plane deformation), 1023 cm^{-1} (amide III C–N stretching) and 1063 cm^{-1} (C–O stretching). Absorption peak at 2874 cm^{-1} indicates the presence of a CH stretch. The peaks between 3500 and 3000 cm^{-1} correspond to the stretching vibrations of free hydroxyl ($-\text{OH}$) and symmetric stretching of the $-\text{NH}$ bonds in the amino group (Bagheri et al. 2014). In case of chitosan treated with

Fig. 1 Characterization of the thin film. **a** SEM images of films prepared from 1.5% CS, **b** 1.5% CS-IO₃, **c** the thin film thickness and **d** FTIR spectra of CS and CS-IO₃ thin film

iodate, the adsorption band for amino group appeared at 3276 cm^{-1} . This band appeared at a higher wave number as compared to pure chitosan (3266 cm^{-1}), indicating the effect of iodate addition on the stretching vibrations of -NH_2 . Chitosan polymer association through bonding is also observed, since the chitosan is positively charged below pH 6 (acidic conditions) and negatively charged when the pH is above 6.5 (Riva et al. 2011). The electrostatic interactions between the amino group of chitosan (positively charged; -NH_3^+) and the iodate (negative charged; -IO_3^-) are quite pronounced (Kurukji et al. 2016).

Property of the edible film

Table 1 contains data acquired during experiments carried out to study the extent of the iodate loss from the edible films. It can be seen that no iodate was discovered in the solution at the given time intervals. It is thus evident that in these edible thin films there are strong interactions between

chitosan polymer and the iodate. This conclusion is further validated by the fact that the contents of iodate in the thin film after 5 min of extraction were found to be in the range of 96.2 ± 1.3 – $104.0 \pm 1.6\text{ mg L}^{-1}$.

Stability of the iodate doped chitosan solution and its edible thin film

The iodate contents (100 mg L^{-1}) in both the iodate doped chitosan solution and its corresponding thin film were also monitored to determine the stability of samples when stored over a period of time. The difference between iodate content at the initial and the final stages was recorded and the amount of iodate that vanished and retained during the storage intervals was calculated as a percentage. The results in Fig. 2a, b show that the retention of iodate in the iodate-doped chitosan solution and its thin film on day one was in a range of 99.71–107.2 and 99.20–107.0% for 0.5% CS-IO₃ and 1.5% CS-IO₃, respectively. Similarly, high

Table 1 The effect of immersion time of iodate-rich edible thin films on the concentration of IO_3^- after extraction ($n = 3$)

Immersion time (min)	% of initial concentration of iodate ^a ($\mu\text{g mL}^{-1}$) $\pm$ SD	
	Before extraction	After extraction
0.5	<i>n.d.</i>	100.8 $\pm$ 1.15
1	<i>n.d.</i>	102.3 $\pm$ 1.34
5	<i>n.d.</i>	104.0 $\pm$ 1.62
10	<i>n.d.</i>	96.96 $\pm$ 1.39
30	<i>n.d.</i>	96.20 $\pm$ 1.31

n.d. not detectable^aMeasured in triplicate ($n = 3$) $\pm$ standard deviation (SD) **Fig. 2** The studies of stability within 4 week. **a** Iodate loss of 0.5% CS- IO_3 solution and thin film, **b** 1.5% CS- IO_3 solution and thin film, **c** weight loss of uncoated and coated with 0.5% CS, CS- IO_3 and **d** with 1.5% CS, CS- IO_3 on chili pepper

percentages of the iodate were found consistently over the next 4 weeks, demonstrating that the iodate-rich chitosan thin film has long term stability and can be stored for longer periods of time without significant erosion of iodate content.

Effect of chitosan treatment on weight loss

Weight loss in fresh fruits is mainly dependent on the respiration rate and moisture evaporation through fruit

skin, which is influenced by postharvest treatment and storage. In our studies, the storage time was confined to 28 days and ambient temperature (30 °C) was maintained throughout. Data given in Fig. 2c, d illustrate that the rate of weight loss was high during first week and increased significantly during second week. Thereafter, from second week to fourth week (end of storage time), the weight loss remained more or less constant. The percentage of weight loss at the end of storage time ranged from 50.7 to 72.8% for the uncoated sample. Corresponding figures for the

coated samples were as follows: 0.5% CS (48.3–75.0%), 0.5% CS-IO₃ (48.7–72.9%), 1.5% CS (47.5–68.7%) and 1.5% CS-IO₃ (48.7–67.0%). From the results, it is clear that weight loss in chitosan-coated fruits was lesser compared to the uncoated chili pepper samples, indicating that the chitosan coating could delay the weight loss of fruits to prolong its shelf life. A closer look at the results reveals that in case of 0.5% CS and CS-IO₃ samples, there were no significant differences between the weight loss data for coated and uncoated samples. However, for samples with 1.5% CS or 1.5% CS-IO₃ loading, the percentage of weight loss in the control sample was significantly higher than that of the coated samples [1.5% chitosan ($P < 0.05$)]. The results indicate that the concentration of chitosan affects the percentage of the weight loss. At lower concentrations, for instance, 0.5% chitosan, the coating is not thick enough and does not provide any barrier against water loss. Whereas, at higher concentrations like 1.5% CS and CS-IO₃, the films are much thicker and completely cover the surface preventing weight loss. Thus, the beneficial effect of chitosan (its action as a barrier for moisture loss from the surface of fresh fruit resulting in decrease in the weight loss) is enhanced when the polymer is used in higher concentrations (Ahlawata et al. 2015). Obviously, a comparatively lower weight loss in the chili pepper fruits coated with iodate doped 1.5% CS should maintain the nutritional values and quality of fruits during storage resulting in better shelf life.

Texture analysis

Changes in the texture of control and coated samples during storage were also compared (Fig. 3). The results of texture evaluation of the uncoated and the coated fruit samples also showed similar trends. Some shrinkage was seen after 1 week of storage at ambient temperature. There were no significant differences in texture of uncoated fruits and the coated ones (both concentrations; 0.5 and 1.5% CS/CS-IO₃) after 1 week of storage. All the samples exhibited

firm surfaces. At the end of first week, all the coated samples shrunk slightly while the control ones exhibited moderate shriveling. After 4 weeks of storage, both of the uncoated (control) and the coated fruits showed signs of decay. However, it was observed that at the end of storage period (28 days), uncoated fruits shriveled to a greater extent than the coated ones. Consequently, in addition to the weight loss, the deterioration of texture can also be avoided, which can be attributed to an antimicrobial component. This is important in context of the better shelf-life and longer storage. However, the beneficial effects of the composite coating are more pronounced when it comes to maintaining firmness and avoiding shriveling of the fruits.

Antioxidant activity and total phenolic

The antioxidant activity (DPPH radical scavenging activity) and total phenolic contents of a chitosan film-coated chili pepper fruits were measured and compared with those of uncoated ones (control sample). The results are shown in Tables 2 and 3. On an average, the values remained constant as the storage period increased. Neither control nor the iodate-coated samples were affected in terms of any of the measured chemical factors until the end of storage (28 days). These results are significant and prove that the film coating on the surface of fruits and vegetables serves to decrease the respiration rate, reduce free radicals and prolong the life of fresh products. Thus, their nutrients can be preserved as far as possible (Wang and Gao 2013).

The iodate on chili pepper sample

Chitosan coatings on fresh chili pepper have traditionally been used to improve quality of foods, because they are considered eco-friendly. Iodate in the coated film was determined using malachite green spectrophotometry. As shown in Fig. 4, the determination was based on the decolorization of MG with a known amount of iodate

Fig. 3 Images of chili pepper fruit with several film treatments over 28 days of storage

Table 2 The effect of different types of thin film coatings on the antioxidant activity of chili peppers determined by the DPPH method

Coating composition	DPPH radical scavenging (%)				
	Start	Week 1	Week 2	Week 3	Week 4
Uncoated	81.24 ± 5.69	73.04 ± 0.12	81.57 ± 2.36	72.37 ± 1.96	74.33 ± 0.15
0.5% CS	80.19 ± 8.97	77.58 ± 2.22	82.76 ± 3.32	80.75 ± 7.64	80.03 ± 5.29
0.5% CS-IO ₃	80.59 ± 6.57	80.66 ± 1.82	81.96 ± 6.96	80.16 ± 8.33	80.98 ± 4.48
1.5% CS	81.19 ± 3.15	81.61 ± 6.20	82.14 ± 2.52	81.78 ± 4.08	80.92 ± 7.34
1.5% CS-IO ₃	81.63 ± 6.27	81.34 ± 5.76	81.86 ± 5.73	80.99 ± 9.32	80.37 ± 2.74

Table 3 The effect of different types of thin film coatings on the total phenolic content of chili peppers

Coating composition	Total phenolic contents (mg CTE/g DW) ^a				
	Start	Week 1	Week 2	Week 3	Week 4
Uncoated	11.75 ± 0.61	11.55 ± 0.27	11.38 ± 0.20	10.72 ± 0.07	10.07 ± 0.07
0.5% CS	11.68 ± 0.32	11.58 ± 0.04	11.31 ± 0.24	10.80 ± 0.27	10.09 ± 0.06
0.5% CS-IO ₃	11.71 ± 0.20	11.54 ± 0.16	11.37 ± 0.09	10.75 ± 0.06	10.01 ± 0.02
1.5% CS	11.53 ± 0.21	11.53 ± 0.16	11.40 ± 0.12	10.83 ± 0.09	10.22 ± 0.00
1.5% CS-IO ₃	11.22 ± 0.10	11.26 ± 0.20	11.36 ± 0.2	10.67 ± 0.05	10.07 ± 0.09

^amg CTE/g DW; milligram of (+)-catechin equivalent per gram of dry weight

Fig. 4 The absorbance of the dye decolorization reaction. The reaction solution consisting of 0.5–2.0 mg L⁻¹ IO₃⁻ in 40 mg L⁻¹ I⁻, 1 mL of 2 mol L⁻¹ H₂SO₄, 1.4 mL of 36.5 mg L⁻¹ dye, 2 mL of 2 mol L⁻¹ CH₃COONa and 5 min equilibration time

(0.5–2.0 mg L⁻¹) under acidic conditions, and the determination of iodate was accomplished by coupling reaction between iodine and MG. The absorbance significantly decreased with an increase in IO₃⁻ concentrations up to 2.0 mg L⁻¹. Consequently, the method could be selectively used to determine only an iodate ion. The limits of detection (LOD) and quantification (LOQ) were also validated at three and ten times the standard deviation of an absorbance signal of 10 reagent blanks (Sricharoen et al. 2016) and were found to be 0.0029 mg mL⁻¹ and 0.0096 mg L⁻¹, respectively, which is lower than the previously reported values (Kaykhaili and Sargazi 2014). The precision data of 0.5 mg L⁻¹ iodate ($n = 15$) were

found to be within the acceptable ranges of RSDs of 4.65 and 9.30% for an intra-day and an inter-day analysis, respectively.

For the determination of iodate content in real sample, the skin of chili pepper (uncoated fruit) was peeled off and extracted prior to analysis. In case of the coated samples, only the coated films on the surface (0.5% CS or 1.5% CS) of chili pepper were peeled off for this evaluation. It was found that for both, the uncoated and the coated fruits, the iodate contents were undetectable. In case of 0.5% CS-IO₃ samples the coated film could not be peeled off as it was too thin. On the other hand, samples coated with 1.5% CS-IO₃, under the same conditions were found to contain 11.45 ± 0.65 mg g⁻¹ iodate (based on weight of dry film). All the results together indicate that this approach can successfully yield iodate rich fruits for daily consumption.

Conclusion

The present work provides a simple, efficient and economic method for obtaining chili pepper fruits coated with edible iodate-rich thin film, starting from inexpensive raw materials. Amalgamation with iodate increases the nutritional values of vegetables and fruits without altering visual appearance, and the resultant coated fruits can help us combat iodine deficiency disorders. Additionally, the study also proves that the coating (1.5% CS/1.5% CS-IO₃) increases shelf-life, helps maintain firmness of the fruit and prevents textural deterioration occurring during management and storage. Consequently, the CS-IO₃ edible thin

film can be potentially used for a wide range of other fruits and vegetables.

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