Effect of maltodextrin on characteristics and antioxidative activity of spray-dried powder of gelatin and gelatin hydrolysate from scales of spotted golden goatfish

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Abstract Characteristics and antioxidative activity of gelatin and gelatin hydrolysate powders from scale of spotted golden goatfish using maltodextrin as a carrier agent at different ratios [1:0, 2:1, 1:1 and 1:2 (w/w)] were investigated. Gelatin hydrolysates with 40 % degree of hydrolysis exhibited the highest antioxidative activity. With increasing maltodextrin proportions, the resulting powders showed an increase in yields, total sugar content and whiteness with coincidental decrease in a^* , b^* -values and browning intensity. Solubility of gelatin powder increased with increase in maltodextrin proportion. Gelatin powder was spherical with smooth surface of hydrolysate varied, regardless of maltodextrin levels. Gelatin hydrolysate powder form, uniform agglomerates when maltodextrin was incorporated. DPPH and ABTS radical scavenging activities and ferric-reducing antioxidant power of gelatin and gelatin hydrolysate decreased when maltodextrin was used as a carrier agent. Thus, maltodextrin levels directly affected characteristics and antioxidative activity of gelatin and gelatin hydrolysate powders.

Keywords Spray-drying · Maltodextrin · Gelatin · Gelatin hydrolysate · Antioxidant activity

Introduction

Gelatin is a fibrous protein obtained from collagenous materials subjected to thermal denaturation or partial degradation. It has been widely used in food and non-food (photographic, cosmetic, and pharmaceutical) industries (Benjakul et al. 2009). Gelatin can be extracted from fish scales, the byproducts from fish dressing or filleting process. Properties of gelatin can be affected by several factors. Drying condition is another factor determining the characteristics and functional properties of fish gelatin (Sae-Leaw et al. 2016a). Although gelatin can exhibit several functional properties, especially gelation, the bioactivity is much lower than its hydrolysates. To enhance bioactivities, hydrolysis is implemented to release bioactive peptides. Gelatin hydrolysate from Nile tilapia skin showed antioxidant and antihypertensive activities (Choonpicharn et al. 2015). Gelatin hydrolysate from blacktip shark skin, prepared using papaya latex enzyme, possessed the increased antioxidant activities when assayed by DPPH and ABTS radical scavenging activity and ferric reducing antioxidant power (Kittiphattanabawon et al. 2012). Gelatin hydrolysate from seabass skin had the increases in antioxidative activity with increasing degree of hydrolysis (DH) (Senphan and Benjakul 2014). Antioxidative activity of seabass skin gelatin was also governed by production processes. Samples hydrolysed during gelatin extraction had higher antioxidative activities than those hydrolysed after gelatin extraction (Sae-Leaw et al. 2016b).

Drying is a process used for food preservation throughout the world. The most common methods applied in the food industry, apart from conventional air drying, are spray drying and freeze drying. Spray drying has been employed widely in food industries to produce dry powders

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and agglomerates. The advantages of spray drying include hygienic conditions during processing, low operational costs, and short contact time (Sagar and Suresh Kumar 2010). Spray-dried gelatin with low water activity and high storage stability was prepared by Sae-Leaw et al. (2016a). During spray drying, sticky products can be generated, thereby adhering to the internal wall of drying chamber. This leads to the lower yield (Hennigs et al. 2001). The use of maltodextrin as an encapsulation or carrier agent in spray drying has been introduced to tackle the problem (Ratanasiriwat et al. 2013). It can also increase the glass transition temperature and stability during storage (Fazaeli et al. 2012).

However, drying conditions e.g. inlet temperature, etc. can affect the property of gelatin in different fashions (Sae-Leaw et al. 2016a). Furthermore, high temperature might induce a loss in bioactivity of hydrolysate, particularly antioxidative activity. Nevertheless, there is a little information on characteristics and bioactivity of gelatin and gelatin hydrolysate prepared by spray drying. The objective of this study was to investigate the effect of maltodextrin levels on the properties and antioxidative activity of spray-dried gelatin and gelatin hydrolysate from spotted golden goatfish scales.

Materials and methods

Chemicals/enzyme

All chemicals were of analytical grade. 2,20 azinobis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS), 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,4,6-tripyridyltriazine (TPTZ) were purchased from Sigma-Aldrich Canada Ltd (Oakville, ON, Canada). Maltodextrin was obtained from Zhucheng Dongxiao Biotechnology CO., LTD (Shandong, China). Alcalase (EC 3.4.21.14, 2.4 L, 2.64 AU/g) was purchased from Brenntag Ingredients Public Company Limited (Bangkok, Thailand).

Collection and preparation of spotted golden goatfish scales

Scales of spotted golden goatfish with an average body weight of 100–120 g/fish were collected from Kingfisher Holding, LTD, Songkhla Province, Thailand. Scales were placed in polyethylene bag and embedded in ice using the scale/ice in ratio of 1:2 (w/w). The sample was transported in polystyrene box to the Department of Food Technology, Prince of Songkla University. Hat Yai, within 1 h.

Pretreatment of spotted golden goatfish scales

Scales were washed using a tap water and drained for 5 min. The scales were then suspended in 0.1 M NaOH for 6 h at the ratio of 1:10 (w/v). The mixture was continuously stirred using an overhead stirrer model W20.n (IKA®-Werke, GmbH & CO.KG, Stanfen, Germany) to remove non-collagenous proteins. The solution was changed every 3 h. Treated scales were washed with tap water until wash water became neutral. Subsequently, the prepared scales were demineralised using 0.75 M HCl with a scale/solution ratio of 1:5 (w/v). The demineralisation was performed at room temperature (28–30 °C) with the continuous stirring for 30 min. Thereafter, the demineralised scales were washed until the neutral pH of wash water was obtained.

Extraction of gelatin

Demineralised scales were mixed with distilled water at a ratio of 1:10 (w/v). The extraction was conducted at 75 °C for 6 h in a temperature controlled-water bath (Model W350, Memmert, Schwabach, Germany). The mixtures were stirred continuously. The mixtures were then filtered using a Buchner funnel, with a Whatman No.4 filter paper (Whatman International, Ltd, Maidstone, England). The filtrate obtained was freeze-dried using a freeze-dryer (CoolSafe 55, ScanLaf A/S, Lyngø, Denmark). Dried gelatin was placed in a polyethylene bag and kept at –20 °C until used.

Preparation of gelatin hydrolysate with different degrees of hydrolysis

Gelatin hydrolysates with different degrees of hydrolysis (DHs) from scale of spotted golden goatfish were prepared as per the method of Kittiphattanabawon et al. (2012) with slight modification. Gelatin (3 g) was dissolved in 80 mL of distilled water. The pH of mixture was adjusted to 8 with 1 M NaOH. The volume of solution was made up to 100 mL by distilled water previously adjusted to pH 8 to obtain a protein concentration of 3 % (w/v). The hydrolysis reaction was started by the addition of Alcalase (EC 3.4.21.14, 2.4 L, 2.64 AU/g, Sigma-Aldrich, Inc., St. Louis, Mo., USA) at various amounts, which were calculated from the plot between log (enzyme concentration) and DH to obtain DH of 10, 20, 30 and 40 %, respectively (Benjakul and Morrissey 1997). After 1 h of hydrolysis at 50 °C, the enzyme was inactivated by heating at 90 °C for 15 min in a temperature controlled water bath (model W350, Memmert, Schwabach, Germany). The mixtures were then centrifuged at 5000g at room temperature for

10 min. The supernatants were freeze-dried using a freeze-dryer (CoolSafe 55, ScanLaf A/S, Lyngby, Denmark). The obtained powders referred to as “gelatin hydrolysate” were placed in polyethylene bag and stored at -20°C . Gelatin hydrolysate samples were subsequently determined for antioxidative activities. Hydrolysate with DH exhibiting the highest activity (40 % DH) was selected for further study.

Determination of antioxidative activity

ABTS radical scavenging activity

ABTS radical scavenging activity was assayed according to the method of Intarasirisawat et al. (2012). A standard curve of Trolox ranging from 50 to 600 μM was prepared. The activity was expressed as μmol Trolox equivalents (TE)/g sample.

DPPH radical scavenging activity

DPPH radical scavenging activity was determined according to the method described by Intarasirisawat et al. (2012). A standard curve was prepared using trolox in the range of 10–60 μM . The activity was expressed as μmol trolox equivalents (TE)/g sample.

Ferric reducing antioxidant power (FRAP)

FRAP was assayed following the method of Benzie and Strain (1996). The standard curve was prepared using Trolox ranging from 50 to 600 μM . The activity was calculated after sample blank subtraction and was expressed as μmol Trolox equivalents (TE)/g sample.

Impact of maltodextrin on properties of dried gelatin and gelatin hydrolysate powder

Gelatin and gelatin hydrolysate were mixed with maltodextrin at different ratios [1:0, 1:1, 2:1 and 1:2 (w/w)]. The mixtures were dissolved in distilled water to obtain a final concentration of 2 % (w/v). The solutions were subjected to spray drying using a spray dryer (SD-06 Basic, North Yorkshire, England) equipped with a spray-drying chamber having the dimension of 500 mm height and 210 mm diameter. A spray nozzle type of two-liquid nozzle (0.5 mm in size) was used. A cyclone separator, a hot-air blower and an exhaust blower were equipped. The solutions were fed by a peristaltic pump at 485 mL/h into the chamber, atomised by the hot air (air velocity of 2 ms^{-1}) from the blower in a downward current flow mode, using the following process conditions: inlet temperature of 180°C , outlet temperature of $80 \pm 2^{\circ}\text{C}$, and

an atomising pressure of 2.8 bars. The resultant powder was blown through the cyclone separator and collected in a container. The powder samples were transferred into a ziplock bag and kept in a plastic vacuum box prior to storage at -40°C . The storage time was not longer than 1 month. All samples were subsequently subjected to analyses.

Analyses

Yield

The production yield was determined gravimetrically. The mass of the dry powder obtained at the end of the process was measured in comparison with that of total solids in the feed. Yield was expressed as a percentage (Xue et al. 2013).

Total sugar content

Total sugar content was determined by phenol–sulfuric acid method using glucose as a standard (Dubois et al. 1956). The standard solution was prepared using glucose solution with different concentrations (0, 0.01, 0.03, 0.05, and 0.07 g/L). Total sugar content was reported as mg/g sample.

Solubility

Samples (2 g) were mixed with distilled water (50 mL). The mixtures were stirred for 15 min at 25°C . Thereafter, the mixtures were centrifuged at 3600g for 15 min at 25°C . The undissolved debris was collected and dried. The soluble fraction was calculated by subtracting undissolved debris from total solid content of the mixture. The solubility was expressed as the percentage, relative to total solid content.

Scanning electron microscopic image

Microstructure of powder was visualised using a scanning electron microscope (SEM) (Quanta400, FEI, Tokyo, Japan) at an accelerating voltage of 15 kV. Prior to visualisation, the samples were mounted on brass stub and sputtered with gold in order to make the sample conductive.

Color

The color of samples was analysed using a Hunter lab colorimeter (Color Flex, Hunter Lab Inc., Reston, VA, USA). L^* , a^* , and b^* , indicating lightness/brightness, redness/greenness and yellowness/blueness, respectively, were

recorded. The colorimeter was calibrated with a white standard. Total difference in color (ΔE^*) was calculated according to the following equation:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^* , Δa^* , and Δb^* are the differences between the corresponding color parameter of the sample and that of the white standard ($L^* = 93.55$, $a^* = -0.84$, $b^* = 0.37$).

Browning index

Browning index of solutions was determined according to the method of Benjakul et al. (2005). Samples (60 mg) were mixed with distilled water (1 mL). Appropriate dilution was made using distilled water. The intermediate and advanced Maillard reaction products were measured using the UV/Vis spectrophotometer at 294 and 420 nm, respectively.

Antioxidative activities

Antioxidative activities were assayed as described previously.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and mean comparisons were carried out using a Duncan's multiple range test. For pair comparison, a *T* test was used. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS for windows: SPSS Inc., Chicago, IL, USA).

Results and discussion

Antioxidative activities of gelatin hydrolysate from scale of spotted golden goatfish as affected by DHs

ABTS radical scavenging activity

ABTS radical scavenging activities of gelatin and gelatin hydrolysates with different DHs are shown in Fig. 1a. The increases in activity were observed in all gelatin hydrolysates with increasing DHs from 10 to 40 % ($p < 0.05$). Activities were 63.85, 75.46, 104.10 and 126.65 $\mu\text{mol TE}/\text{mg sample}$ for hydrolysates with 10, 20, 30 and 40 % DH, respectively. In general, the increases in ABTS radical scavenging activity were found in hydrolysate, compared with gelatin. The result suggested that peptides produced in hydrolysates with various DHs might be different in term

Fig. 1 ABTS radical scavenging activity (a), DPPH radical scavenging activity (b), and ferric reducing antioxidant power (FRAP) (c) of gelatin and gelatin hydrolysates with different DHs. Bars represent standard deviation ($n = 3$). Different letters on the bars denote significant differences ($p < 0.05$)

of amino acid composition, sequence and chain length. Generally, all hydrolysates contained peptides or proteins, which were hydrogen donors and could react with the radicals to convert them to more stable products, thereby terminating the radical chain reaction (Khantaphant and Benjakul 2008). The results indicated that antioxidative peptides were produced during the hydrolysis. Phanturat et al. (2010) reported that gelatin hydrolysates from bigeye snapper skin with DH ranging from 5 to 25 % prepared using pyloric caeca extract from bigeye snapper had the increased ABTS scavenging activity with increasing DH. Gelatin hydrolysates from blacktip shark skin prepared using papaya latex enzyme with different DHs (10–40 %

DH) had increased ABTS scavenging activity with increasing DH (Kittiphattanabawon et al. 2012). Thus, gelatin hydrolysates, especially at 40 % DH, had the ability to scavenge free radicals, thereby preventing lipid oxidation via a chain breaking reaction.

DPPH radical scavenging activity

DPPH radical scavenging activities of gelatin and gelatin hydrolysate with different DHs (10, 20, 30 and 40 % DH) are shown in Fig. 1b. Gelatin hydrolysates showed an increase in DPPH radical scavenging activity when DH increased ($p < 0.05$). Gelatin hydrolysates with 40 % DH exhibited the highest activity (7.24 $\mu\text{mol TE/mg sample}$). For gelatin solution without hydrolysis, a much lower DPPH radical scavenging activity (0.494 $\mu\text{mol TE/mg sample}$) was found, compared with that obtained in the gelatin hydrolysates. During hydrolysis, a wide variety of smaller peptides and free amino acids were generated, depending on enzyme specificity (Khantaphant and Benjakul 2008). Changes in size, level and composition of free amino acids and small peptides affected the antioxidative activity (Wu et al. 2003). Therefore, gelatin hydrolysate obtained could donate hydrogen atom to free radicals. As a result, those radicals became more stable diamagnetic molecule, leading to the termination of the radical chain reaction (Binsan et al. 2008). Nevertheless, the efficiency in hydrogen donation of peptides produced was governed by DHs.

Ferric reducing antioxidant power (FRAP)

Ferric reducing antioxidant power (FRAP) of gelatin and gelatin hydrolysates with different DHs are shown in Fig. 1c. FRAP of gelatin and gelatin hydrolysates with % DH of 10, 20, 30 and 40 was 0.85, 2.38, 3.47, 7.39 and 8.42 $\mu\text{mol TE/mg sample}$, respectively. The results were in agreement with DPPH and ABTS radical scavenging activities, the activities increased as DH increased. FRAP is generally used to measure the capacity of a substance in reducing TPTZ–Fe(III) complex to TPTZ–Fe(II) complex (Benzie and Strain 1996; Binsan et al. 2008). The result suggested that gelatin hydrolysate with 40 % DH possibly contained higher amounts of peptides, which were able to donate electrons to free radicals, thereby terminating the chain reaction. The greater reducing power indicated that hydrolysates could donate the electron to the free radical, leading to the prevention or retardation of propagation (Klompong et al. 2008). The DH determines the peptide chain length as well as the exposure of terminal amino groups of products obtained (Thiansilakul et al. 2007). Changes in size, level and composition of free amino acids of peptides also affected the antioxidative activity (Wu

et al. 2003). Therefore, gelatin hydrolysate especially that with 40 % DH, could provide the electron to radicals via reduction process, thereby impeding the oxidation.

Effect of maltodextrin on spray-dried powder of gelatin and gelatin hydrolysate

Yields

The yields of gelatin and gelatin hydrolysate powder containing maltodextrin at various ratios [1:0, 2:1, 1:1, and 1:2 (w/w)] are presented in Table 1. Without maltodextrin, the yields of 19.32 and 15.53 %, respectively, were obtained for gelatin and gelatin hydrolysate powder. Gelatin hydrolysate with a shorter chain might be lost with ease during spray drying. When maltodextrin proportions increased, the yields of both gelatin and gelatin hydrolysate powders increased ($p < 0.05$). Gelatin and gelatin hydrolysate powder containing maltodextrin at ratio 1:2 (w/w) had the highest yields (35.64 and 32.43 %), compared to other ratios ($p < 0.05$). Overall, gelatin hydrolysate powder had the lower yield, in comparison with gelatin powders, regardless of maltodextrin proportion used. Generally, gelatin and gelatin hydrolysate powders are hygroscopic products. However, gelatin hydrolysate was more hygroscopic due to the higher content of charged N- or C-termini. During drying at high temperatures, the greater evaporation of water proceeded, thus reducing the moisture of the powders and conversely increasing the capture of water molecules by the samples. When a dried powder was exposed to the environment, it rapidly assimilated the moisture. As a result, the product might be attached inside the drying chamber (Suhimi and Mohammad 2011). In the presence of maltodextrin, maltodextrin particles were apparently bigger than the particles constituting the soluble gelatin and gelatin hydrolysate. Thus, maltodextrin addition directly increased the bulk densities, thereby lowering the loss of soluble solids. Caliskan and Nur Dirim (2013) found that the addition of maltodextrin increased the product yield by preventing the adhesion of sumac extract on the chamber walls. Therefore, maltodextrin had the influence on yields of gelatin and gelatin hydrolysate powders.

Total sugar contents

Total sugar contents in gelatin and gelatin hydrolysate powders containing maltodextrin at different ratios are shown in Fig. 2. Both gelatin and gelatin hydrolysate powders showed an increase in total sugar content with increase in maltodextrin proportions. Gelatin hydrolysate mixed with maltodextrin at a ratio 1:2 (w/w) showed the highest total sugar content, compared to others ($p < 0.05$).

Table 1 Solubility and colour of gelatin and gelatin hydrolysate powder from spotted golden goatfish scales with different sample/maltodextrin ratios

Samples	Gelatin: maltodextrin (w/w)				Gelatin hydrolysate: maltodextrin (w/w)			
	1:0	2:1	1:1	1:2	1:0	2:1	1:1	1:2
L*	94.83 ± 0.43Db	95.73 ± 0.08Eb	96.75 ± 0.35Fb	96.6 ± 0.44Fb	87.29 ± 0.66Aa	91.39 ± 0.56Ba	92.54 ± 0.24Ca	93.02 ± 0.87Ca
a*	−0.26 ± 0.06Gb	−0.45 ± 1.05Bb	−0.42 ± 0.86Ca	−0.41 ± 0.05Ca	−0.14 ± 0.97Fa	−0.77 ± 0.39Aa	−0.35 ± 0.57Db	−0.33 ± 0.12Eb
b*	5.9 ± 0.83Da	2.50 ± 0.46Aa	2.21 ± 0.52Aa	1.92 ± 0.81Aa	14.53 ± 1.02Fb	11.80 ± 0.29Eb	5.52 ± 0.91Bb	5.69 ± 0.11Cb
ΔE	5.77 ± 0.51Ca	3.80 ± 0.15Aa	4.29 ± 0.66Ba	4.14 ± 0.53Ba	9.24 ± 0.24Db	9.42 ± 1.23Db	5.19 ± 0.41Cb	5.39 ± 0.63Cb
Yield (%)	19.32 ± 0.83Bb	23.45 ± 0.32Db	27.44 ± 0.74Fb	35.64 ± 0.21Hb	15.53 ± 0.56Aa	18.54 ± 0.61Ca	24.64 ± 0.87Ea	32.43 ± 0.95Ga
Solubility (%)	11.70 ± 0.81Aa	15.35 ± 0.83Ba	17.54 ± 0.45Ca	26.88 ± 0.76Da	99.87 ± 0.64Fb	99.12 ± 0.96Fb	97.73 ± 0.69Eb	97.43 ± 0.52Eb

Values are expressed as mean ± SD ($n = 3$)

Different uppercase letters within the same row indicate significant differences ($p < 0.05$)

Different lowercase letters within the same row under the same sample/maltodextrin ratio indicate significant difference ($p < 0.05$)

Fig. 2 Total sugar content of gelatin and gelatin hydrolysate powders from the scale of spotted golden goatfish using different sample/maltodextrin ratios. Bars represent the standard deviation ($n = 3$). Different uppercase letters (A, B, C and D) on the bars within the same samples indicate significant differences ($p < 0.05$). Different lowercase letters on the bars indicate significant differences ($p < 0.05$). Different uppercase letters (X and Y) on the bars within the same sample/maltodextrin ratio indicate significant differences ($p < 0.05$)

In the absence of maltodextrin, the lowest total sugar content was noticed ($p < 0.05$). Maltodextrin consists of D-glucose units connected in chains of various lengths. It is typically composed of a mixture of chains that vary from 3 to 17 glucose units. The glucose units are primarily linked with α (1 $\rightarrow$ 4) glycosidic bonds (Barcelos et al. 2014). In the present study, the presence of maltodextrin was determined in term of total sugar using phenol–sulfuric acid method. The method depends on dehydration of hydrolysed saccharides to furfural derivatives during reaction with concentrated sulfuric acid (DuBois et al. 1956; Albalasmeh et al. 2013). Further reaction of the furfural derivatives with phenol forms colored complexes that absorb light in the visible range, with a maximum absorbance at a wavelength of 490 nm (Albalasmeh et al. 2013). However, there was no difference in total sugar content between gelatin and gelatin hydrolysate powders when the same sample/maltodextrin ratio was used ($p > 0.05$). The result confirmed the presence of maltodextrin in the powders, in which the content varied, depending on the proportion of maltodextrin added.

Solubility

Solubility of gelatin and gelatin hydrolysate powders containing maltodextrin at various ratios is presented in Table 1. Gelatin powder showed the low solubility at room temperature. The increase in solubility was found when the maltodextrin proportion increased ($p < 0.05$). Maltodextrin is more likely hydrophilic in nature, thereby enhancing the water solubility of powder. In general, gelatin is able to completely solubilised when the sufficient heat is applied.

Heat could destroy the weak bonds stabilising the gelatin aggregate, particularly hydrogen bond. As a result, the gelatin could be dissolved readily. When it was dissolved at room temperature, a large proportion of gelatin was still undissolved as indicated by low solubility. High solubility of all gelatin hydrolysate powder was observed, regardless of gelatin hydrolysate/maltodextrin ratio. Hydrolysate generally has an excellent solubility, especially with high degree of hydrolysis (Klompong et al. 2007). High solubility of hydrolysates was due to the generation of low molecular weight peptides, which had more polar residues than the parent proteins. The enhanced ability to form hydrogen bonds with water increased the solubility of hydrolysate (Giménez et al. 2009). Enzymatic hydrolysis potentially affects the molecular size and hydrophobicity, as well as the polar and ionisable groups of protein hydrolysates (Kristinsson and Rasco 2000). It was noted that maltodextrin had no marked impact on the solubility of resulting gelatin hydrolysate powders, suggesting high solubility of both gelatin hydrolysate and maltodextrin.

Color

The color of gelatin and gelatin hydrolysate powder from spotted golden goatfish scales using maltodextrin as a carrier agent at different ratios expressed as L^* , a^* and b^* is shown in Table 1. At all ratios of sample/maltodextrin used, gelatin powder exhibited higher L^* -value (lightness) than gelatin hydrolysate counterpart. Higher L^* -values were found when maltodextrin was incorporated. No difference in L^* -value was observed between powders with sample/maltodextrin ratios of 1:1 and 1:2 ($p > 0.05$) for both gelatin and gelatin hydrolysate. a^* and b^* -values and ΔE^* of gelatin hydrolysate powder were higher than those of gelatin counterpart at all ratios of sample/maltodextrin. Those values decreased with increasing maltodextrin proportion used. Carbonyl groups in maltodextrin might undergo Maillard products with free amino groups of gelatin hydrolysate to a higher content, compared to gelatin. The Maillard reaction involved in the formation of brown pigments comprises the condensation between a carbonyl group of reducing sugars, aldehydes or ketones and an amine group of free amino acids (such as amino acids, peptides and proteins) or any nitrogenous compound (Kim and Lee 2009). As a consequence, gelatin powder more likely had higher whiteness with less yellowness, compared to gelatin hydrolysate powder. Therefore, maltodextrin had the influence on color of gelatin and gelatin hydrolysate powders.

UV-absorbance and browning intensity

The highest browning of gelatin and gelatin hydrolysate powders from spotted golden goatfish scales was obtained

Fig. 3 Absorbance at 420 and 294 nm of gelatin and gelatin hydrolysate powders from the scale of spotted golden goatfish using different sample/maltodextrin ratios. Bars represent the standard deviation ($n = 3$). Different uppercase letters (A, B, C) on the bars within the same samples indicate significant differences ($p < 0.05$). Different lowercase letters on the bars indicate significant differences ($p < 0.05$). Different uppercase letters (X and Y) on the bars within the same sample/maltodextrin ratio indicate significant differences ($p < 0.05$)

in the absence of maltodextrin as indicated by the highest A_{294} and A_{420} (Fig. 3). The gelatin hydrolysate powders containing different levels of maltodextrin showed higher browning intensity than gelatin powder. Gelatin hydrolysate had higher content of free amino group, which readily underwent glycation. As a consequence, browning occurred to a higher extent, compared with gelatin. A_{294} has been used to indicate the formation of an uncoloured compound, which was reported to be the precursor of the Maillard reaction (Ajandouz et al. 2001; Lerici et al. 1990). Lerici et al. (1990) found that heat treatment of a glucose–glycine mixture caused the marked increase in A_{294} . Additionally, the increase in A_{420} was used as an indicator for browning development in the final stage of the browning reaction (Ajandouz et al. 2001; Benjakul et al. 2005). Gelatin and gelatin hydrolysate powders had lower browning intensity as the maltodextrin at higher ratio was incorporated. This was coincidental with the higher whiteness (L^* -value) and lower a^* and b^* -values of powder when maltodextrin was used as a carrier agent (Table 1).

Therefore, the use of maltodextrin could improve the whiteness of gelatin and gelatin hydrolysate powder in a dose dependent manner.

Scanning electron microscopic image

Microstructures of gelatin and gelatin hydrolysate mixed with maltodextrin at different sample/maltodextrin ratios are shown in Fig. 4. Gelatin powders were spherical in shape and varying sizes were noticeable. In general, the smaller particles had the shrinkage on the surface. There was no marked difference in morphology between gelatin powders with different sample/maltodextrin ratios. When the drying temperature was sufficiently high, moisture was evaporated very quickly and the surface become dry and hard. Hollow could not deflate when vapor condensed within the vacuole as the particles moves into cooler regions of the dryer (Suhimi and Mohammad 2011). Wrinkled surface was developed when rapid crust formation took place for droplets during the early stage of drying. All gelatin hydrolysate samples had smaller particles, compared with all gelatin counterpart, regardless of sample/maltodextrin ratio. Short chain peptides might not agglomerate into the large particles as indicated by small particles. In the presence of maltodextrin, the larger agglomerate was formed. In the presence of maltodextrin

with longer chain length, higher ability to agglomerate along with gelatin hydrolysate during the drying process was obtained. Maltodextrin can significantly increase the glass transition temperature and reduce the hygroscopicity of dried products (Goula and Adamopoulos 2008). However, there was no difference in morphology of all gelatin hydrolysate powders when different sample/maltodextrin ratios were used.

Antioxidant activities

Antioxidant activities of gelatin and gelatin hydrolysate powders using maltodextrin as a carrier agent at different levels are shown in Fig. 5. The higher ABTS radical scavenging activity, DPPH radical scavenging activity and ferric reducing antioxidant power (FRAP) were found in gelatin hydrolysate powder, in comparison with those of gelatin powder when the same sample/maltodextrin was used ($p < 0.05$). Gelatin hydrolysates are breakdown products of enzymatic conversion of gelatin into smaller peptides, which are composed of free amino acids and short chain peptides exhibiting biological activity. DPPH and ABTS radical scavenging activities have been used to indicate the ability of antioxidants to donate a hydrogen atom or an electron to stabilise radicals, by converting it to the non-radical species (Kittiphattanabawon et al. 2012). Moreover, FRAP is

Gelatin : Maltodextrin

Gelatin hydrolysate : Maltodextrin

Fig. 4 Microstructures of gelatin and gelatin hydrolysate powders from the scale of spotted golden goatfish using different sample/maltodextrin ratios. Magnification: $\times 2500$

Fig. 5 Antioxidant activity of gelatin and gelatin hydrolysate powders from the scale of spotted golden goatfish using different sample/maltodextrin ratios. Bars represent the standard deviation ($n = 3$). Different uppercase letters (A, B, C and D) on the bars within the same samples indicate significant differences ($p < 0.05$). Different lowercase letters on the bars indicate significant differences ($p < 0.05$). Different uppercase letters (X and Y) on the bars within the same sample/maltodextrin ratio indicate significant differences ($p < 0.05$)

generally used to measure the capacity of a substance in reducing TPTZ–Fe(III) complex to TPTZ–Fe(II) complex. The result suggested that gelatin hydrolysate contained higher amounts of peptides than gelatin. Those peptides were able to donate electrons to free radicals, thereby terminating the chain reaction (Kittiphattanabawon et al. 2012). However, the conformational changes of peptides in gelatin and gelatin hydrolysate might occur to some extent during the spray-drying process at high temperature. The changes in composition of free amino acids and/or peptides could affect the antioxidant activity (Thiansilakul et al. 2007; Sai-Ut et al. 2014). When maltodextrin was incorporated, the resulting powder of gelatin and gelatin hydrolysates showed the lower antioxidative activity. This suggested the dilution effect of maltodextrin present in gelatin and gelatin hydrolysate powders. Although maltodextrin yielded the powder with whiter

colour, its incorporation directly lowered antioxidative activity of resulting powders.

Conclusion

Maltodextrin used as a carrier agent for gelatin and gelatin hydrolysate was able to increase the yield and improve the whiteness of gelatin and gelatin hydrolysate powders. All gelatin hydrolysate powder containing maltodextrin had higher solubility and antioxidant activity, compared with gelatin counterpart. However, maltodextrin exhibited the dilution effect on bioactivity of gelatin hydrolysate. Thus, gelatin hydrolysate powder having high antioxidative activity with high yield could be prepared using maltodextrin as a carrier agent at a ratio 2:1 (w/w).

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