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Foam-mat dried Japanese threadfin bream (*Nemipterus japonicus*) powder with methyl cellulose as the foaming agent: Physicochemical and functional properties

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Abstract

Minced meat of Japanese threadfin bream (*Nemipterus japonicus*) was foam-mat dried at 70 and 80°C using methyl cellulose (MC) as the foaming agent at concentrations of 0.0, 0.5, 1.0, and 1.5% w/w. The objective was to determine the effect of drying temperature and amount of foaming agent incorporated on the physicochemical and functional properties of the powdered samples. Fish powders had a water activity (a_w) of < 0.40, which significantly increased ($p < 0.05$) with increasing MC concentrations and drying temperatures. Protein solubility (PS) and water holding capacity (WHC) were inversely correlated with the drying temperature (r = -0.943 and -0.749, respectively). Emulsification property had a strong inverse correlation with MC (r = -0.839) as compared to temperature (r = 0.462). The TBARS and FFA values of the fish powders dried at 70°C were significantly lower than at 80°C ($p < 0.05$). No significant differences were obtained in their fat and ash contents, except for crude protein, which was significantly higher in the fish powder dried at 70°C. Drying at 70°C resulted in overall superior powder properties, with 0.5% MC being the best treatment.

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Introduction

Threadfin bream (*Nemipterus japonicus*, Bloch, 1791) is the most abundant species belonging to the family Nemipteridae. They are widespread in the western Indo-Pacific, including the coast of East Africa, the Red Sea, and the Persian Gulf, as well as the Indo-Malay Archipelago (Farivar *et al.*, 2017). Threadfin bream has white meat, smooth texture, fresh seaweed odour, sweet flavour, and low fat, thus making it suitable for fish protein development (Shaviklo, 2015). A stable fish powder will further enhance the utilisation of this species in a variety of fish-based products such as fish crackers, fish cakes, and fish floss, besides reducing post-harvest losses. Spray drying and freeze drying can be used to produce fish powder; however, foam-mat drying (FMD) is a simple and cost-effective alternative to other drying techniques (Buljat *et al.*, 2019). In addition, FMD has lower drying temperature than conventional drying methods (Sharif *et al.*, 2018). Fish meat is high in unsaturated lipids, and easily oxidised; therefore, drying it at lower temperature is recommended.

Limited literature is available on the FMD of seafood, except for one on shrimp (Azizpour *et al.*, 2016; Hamzeh *et al.*, 2019). FMD is suitable for drying heat-sensitive raw materials (Mangueira *et al.*, 2021). Minimum quality changes could also be obtained by FMD due to the relatively fast drying rate (Javed *et al*., 2018). Higher drying rate of the foamed materials is due to the increased moisture movement by capillaries through the liquid films separating foam bubbles (Qadri *et al.*, 2020). The increase in surface area due to the foam formation facilitates moisture removal during drying. The liquid-solid foods are added to foaming/stabilising agents (a surfactant), whipped into a stable foam, and oven-dried (Mangueira *et al.*, 2021). The primary prerequisite for effective foam drying is a stable gas-liquid foam, where thermal stability is essential (Sangamithra *et al.*, 2015). The collapse of foam

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prolongs the drying time, lessens the rehydration, and degrades the nutritional value of the food and other important properties such as texture, colour, and flavour (Fernandes *et al*., 2013). Changes in the rheological properties of the foam or an increase in the glass transition temperature of the product occur when foaming or stabilising agents are added, thus preventing the collapse of the foam during drying (Ratti and Kudra, 2006). Therefore, the selection of foaming agent and drying temperature (40 - 90°C) is crucial in producing satisfactory FMD products, such as fish powders, since they contain lipids and proteins (Hardy and Jideani, 2017). Foams that do not collapse for at least 60 min at room temperature (25 ± 1°C) are considered to be mechanically and thermally stable (Buljat *et al*., 2019).

Protein-based foaming agents, such as egg white and soy protein, are commonly used in different types of foods; however, egg white foams are unstable and normally collapse after 20 min of whipping (Mounir, 2017). Likewise, the instability of soy protein foams over time has also been reported (Martínez *et al*., 2009). Methyl cellulose (MC) is a polysaccharide foaming agent that readily adsorbs at the air-water interface, reducing interfacial tension, and thus produces stable foams (Khamjae and Rojanakorn, 2018), and stabilises protein foams by a thickening or gelling effect (Klitzing and Müller, 2002). MC concentration of 0.25 - 2% has been suggested for FMD (Hardy and Jideani, 2017). MC has been used as a foaming agent at different concentrations, such as 0.25 - 1% for papaya powder (Kandasamy *et al.*, 2012), 0.5 - 2% for yoghurt powder (Krasaekoopt and Bhatia, 2012), 1 - 2% for gấc fruit powder (Auisakchaiyoung and Rojanakorn, 2015), 0.75 - 2.25% for passion fruit powder (Khamjae and Rojanakorn, 2018), and 1 - 2% for sour cherry powder (Abbasi and Azizpour, 2016). Since fish meat is rich in protein, the use of MC could produce a net attraction between the two macromolecules, as suggested by Carp *et al*. (2004).

Currently, there is a paucity of literature on the study of foam-mat dried fish powder. Threadfin bream foams were dried at 60 and 90°C as initial trials, but the results were unsatisfactory. Consequently, the present study aimed to investigate the effect of drying at 70 and 80°C, and the amount of MC (0.0 - 1.5%) as the foaming agent ,on the physicochemical and functional properties of FMD threadfin bream powder.

Materials and methods

Sample preparation

Fresh Japanese threadfin bream purchased from a fish market in Selangor, Malaysia, were immediately transported to the laboratory on ice. The fish was washed, the head and tail were removed, degutted, and deboned using a deboning machine (fish meat separator, Model FD 6, Malaysia). The minced fish meat obtained was placed in a plastic bag, and frozen at -18°C until the preparation of foams. Food grade methyl cellulose (MC; Scienfield Expertise PLT, Selangor, Malaysia) at 0.0, 0.5, 1.0, and 1.5% w/w concentrations were added to each treatment (250 g of minced fish meat). Initially, the amount of MC powder (g) required to attain each desired concentration was hydrated by dissolving in distilled water (1 g of MC in 33 of mL distilled water), and stirred continuously using a magnetic stirrer until a homogeneous solution was obtained, then refrigerated at 4°C for 18 h, as reported by Abbasi and Azizpour (2016). To prepare the foam samples, the definite amount of MC solutions, minced fish (250 g), and distilled water (750 mL) were transferred to a mixing bowl. The mixture was whipped using a kitchen mixer (HR7915 Philips, China) with a whisk beater attachment at speed 7 for 10 min.

Fish powder using foam-mat drying

The foamed samples with an initial moisture content of about 95% (wet basis) were layered (334 ± 1 g) on a non-stick carbon steel tray (37 × 25.5 × 1.6 cm) with a thickness of 5.0 ± 0.2 mm, and dried in a hot air oven (UF110 Memmert, Germany) at two levels of drying temperatures (70 and 80°C). When the moisture content of the foam samples reached below 5.0% on a dry basis (db), the drying was halted, and the trays were taken out of the dryer. The dried foam mats were ground in a mixer (MX-897GM National, Malaysia) for 45 s, and sieved through an 80-mesh plastic strainer. The fish powder was packaged in airtight plastic jars wrapped with aluminium foil, and refrigerated at 4°C until further analyses.

Fish oil extraction

The fish oil was extracted from the fish powder based on Kinsella *et al*. (1977). Briefly, fish powder (10 g) was blended with a mixture of distilled water (40 mL), methanol (100 mL), and chloroform (50 mL) for 2 min. Additional chloroform (50 mL) and distilled water (50 mL) were added to the mixture, and blended for 30 s. The mixture was filtered through Whatman No. 1 filter paper on a No. 3 Buchner funnel with the aid of suction (water aspirator). The filtrate was transferred to a 500-mL graduated cylinder for phase separation. The lower clear phase was poured into a round-bottom flask, and concentrated with a vacuum rotary evaporator. The extracted fish oil was used to evaluate the peroxide value and free fatty acid.

Physicochemical and functional analyses

Proximate composition

The standard AOAC (2005) procedures were followed to determine the proximate composition of the fish powder samples. The moisture content was determined by drying samples at 105°C for 7 h. The Kjeldahl method was used to determine the protein content (% Nitrogen × 6.25), and for the fat content, the Soxhlet extraction method was used. For the ash content, 3 g of the sample was incinerated in a furnace at 550°C until no black particle was present, as prescribed in the AOAC (2005) method. The carbohydrate content was determined by calculating the percentage difference as shown in Eq. 1:

$$\text{Carbohydrate} = 100\% - (\%\text{moisture} + \%\text{ash} + \%\text{crude protein} + \%\text{crude fat}) \quad \text{(Eq. 1)}$$

All proximate components were analysed in triplicate.

pH

Three grams of fish powder were blended with 30 mL of distilled water to form a homogenous solution. The pH of the sample solution was measured using a Sartorius PB-10 pH meter (Sartorius, Germany), which has been pre-calibrated. All samples were analysed in triplicate.

Water activity

The water activity (a_w) was determined using a water activity meter (AquaLab series 3 TE model, Decagon Devices Inc., Pullman, WA, USA). The instrument was first calibrated with distilled water (a_w = 1.000 ± 0.003). Approximately 1.5 g of the fish powder sample was filled in the disposable sample cup, and inserted into the sample drawer. The a_w was measured automatically, and the readings were recorded in 5 min or less, providing ± 0.001 a_w accuracy. The temperature of all samples was maintained at 24°C during the analysis. All samples were analysed in triplicate.

Protein solubility

The protein solubility (PS) was determined according to Venugopal *et al*. (1996) with a slight modification, in which the centrifugation time was extended to 7 min instead of 5 min. Fish powder (1 g) was added to 40 mL of 3% NaCl solution, and homogenised with a Vortex mixer (VTX-3000L Mixer Uzusio, LMS Japan) for 2 min. The mixture was centrifuged (Model 3740, Japan) at 6,300 *g* for 7 min, and the supernatant was collected for the protein estimation. The percentage of PS was calculated using Eq. 2:

$$\text{PS (\%)} = \frac{\text{Protein content in the supernatant}}{\text{Total protein content in the sample}} \times 100 \quad \text{(Eq. 2)}$$

Water holding capacity

The water holding capacity (WHC) was determined according to Miller and Groninger (1976). In a 50-mL centrifuge tube, 1 g of fish powder sample was added to 40 mL of distilled water, and homogenised for 5 min with a Vortex mixer (VTX-3000L Mixer Uzusio, LMS Japan). Tubes were then centrifuged (Model 3740, Japan) at 7,500 *g* for 7 min, and the supernatant was transferred into a 50-mL calibrated beaker. The volume of the supernatant was subtracted from the original 40 mL. The WHC was reported in terms of mL of water held by 1 g of powder.

Emulsification property

The method of Yasumatsu *et al*. (1972) was adopted to determine the emulsification property (EP). Fish powder sample (1 g), distilled water (25 mL), and corn oil (25 mL; Vecorn, Malaysia) were blended for 1 min. The suspension was then poured into a calibrated centrifuge tube (50 mL) and centrifuged (Model 3740, Japan) at 7,500 *g* for 7 min. The emulsification property was calculated using Eq. 3:

$$\text{EP (\%)} = \frac{\text{Emulsion volume after centrifugation}}{\text{Emulsion volume before centrifugation}} \times 100 \quad \text{(Eq. 3)}$$

Peroxide value

The determination of peroxide value (PV) was done according to Pearson (1976). The extracted fish oil (1 g) was weighed into a clean, dry boiling tube, followed by the addition of 1 g of potassium iodide powder and 20 mL of glacial acetic acid with a 2:1 chloroform mixture. Then, the boiling tube was placed in boiling water for 30 s. The content was then quickly transferred into a conical flask containing 20 mL of 5% potassium iodide solution. The tube was rinsed twice (using 25 mL of distilled water each time), pooled into the conical flask, and titrated against 0.002 mol/L $Na_2S_2O_3$ solution using 0.5 mL of starch as an indicator. Titration was carried out until the blue colour vanished. A blank was also performed at the same time. The PV was reported as a milliequivalent peroxide/kg sample.

Thiobarbituric acid reactive substances

Thiobarbituric acid reactive substances (TBARS) were determined according to Woyewoda *et al*. (1986). Fish powder (10 g) was blended with 35 mL of distilled water for 2 min, and transferred into a round bottom flask containing 0.05 g of each propyl gallate and EDTA. The flask was filled with distilled water to a total weight of 105 g. Nitrogen gas was bubbled through the solution, followed by the addition of 95 mL of 4 mol/L HCl. The whole mixture was then distilled, and the distillate was collected for analysis. For the standard curve, 0.0, 0.4, 0.8, 1.2, 1.6, and 2.0 mL of TEP solutions were pipetted accurately into screw-capped tubes, and the volume was adjusted to 5 mL with distilled water. Then, 5 mL of distillate (replaced with 5 mL of distilled water for the blank) and 5 mL of TBA reagent were added to the tube. The tubes were capped tightly, mixed with a Vortex mixer, heated in a water bath (95°C) (Memmert, Germany) for 45 min, and cooled in tap water for 10 min. The absorbance was measured at 538 nm using a G10S UV-Vis Spectrophotometer (Madison WI, USA). The result was expressed as μmol malondialdehyde (MDA) per kg of fish sample.

Free fatty acid

The free fatty acid (FFA) was determined according to Woyewoda *et al*. (1986). The extracted fish oil (1 g) and 75 mL of chloroform: isopropyl alcohol: methanol solution (2:2:1) were added together in a 125-mL Erlenmeyer flask, and swirled to dissolve the lipid. The mixture was then titrated with 0.05 mol/L NaOH solution after four drops of meta-cresol purple indicator were added. A blank containing all reagents except the sample was also prepared and titrated.

Statistical analysis

Statistical analysis of the data was carried out by two-way analysis of variances (ANOVA) with the Tukey's test using the Minitab 18 software (Minitab Inc., State College, Pennsylvania, USA) at a significance level of $p < 0.05$. The relationship between dependent variables was performed using Pearson's correlation. The treatment that presented the most desirable properties was then selected as the best treatment.

Results and discussion

Proximate composition

Table 1 shows the proximate composition of FMD fish powders. The temperature of drying and percentage of MC used affected the proximate composition of the fish powders. The drying kinetics of threadfin bream minced meat foams have been discussed in our previous study (Mohamed *et al.*, 2022). The drying time took 270 min at 80°C, and 450 min at 70°C to achieve the desired moisture content of below 5.0% (db). Our previous study also reported that majority of the moisture content of the samples was removed after 120 and 180 min of drying at 80 and 70°C, respectively, due to the thicker layer of dried samples in the initial drying stages. The foam layer became thinner with drying time, until it reached a certain thickness which improved the heat transfer efficiency. A study by Hamzeh *et al*. (2019) on drying shrimp foam reported that increasing the foam thickness from 4 to 8 mm resulted in a longer drying time. The thinner foam layer provides more heat penetration, and faster moisture transfer. However, a higher drying temperature results in a greater drying rate and a shorter drying time; therefore, the temperature is the main influence on drying time. Foods with less than 5.0% moisture content exclude the growth of microorganisms and the occurrence of chemical reactions. The stability of food is highly linked to its moisture level, and in particular, its water activity (Franco *et al*., 2016). Although the lower drying temperature resulted in a longer drying time, a significant ($p < 0.05$) lower moisture content was obtained in samples dried for 450 min. A similar conclusion was made by Siddique and Wright (2003) where longer drying times resulted

Table 1. Effect of drying temperatures and methyl cellulose concentrations on proximate composition, pH, and water activity (a_w) of FMD Japanese threadfin bream (*Nemipterus japonicus*) powder.

T (°C)	MC (%)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	CHO (%)	pH	a_w
70	0.0	3.42 ± 0.10^{d}	86.72 ± 0.45^{a}	4.04 ± 0.07^{a}	5.10 ± 0.07^{a}	0.83 ± 0.54^{c}	6.43 ± 0.02^{a}	0.248 ± 0.01^{e}
	0.5	3.46 ± 0.12^{d}	85.17 ± 1.27^{ab}	4.52 ± 0.37^{a}	5.11 ± 0.17^{a}	1.86 ± 1.18^{c}	6.41 ± 0.02^{ab}	0.251 ± 0.01^{e}
	1.0	3.67 ± 0.20^{d}	84.39 ± 1.02^{abc}	4.59 ± 0.48^{a}	5.11 ± 0.15^{a}	3.37 ± 0.98^{bc}	6.40 ± 0.01^{b}	0.275 ± 0.01^{d}
	1.5	3.79 ± 0.07^{cd}	82.54 ± 1.05^{abcd}	4.93 ± 0.41^{a}	5.25 ± 0.10^{a}	3.63 ± 1.11^{abc}	6.39 ± 0.01^{b}	0.289 ± 0.01^{c}
80	0.0	3.94 ± 0.15^{bcd}	84.58 ± 1.62^{ab}	3.93 ± 0.83^{a}	5.03 ± 0.23^{a}	2.67 ± 2.05^{bc}	6.34 ± 0.02^{c}	0.358 ± 0.02^{b}
	0.5	4.40 ± 0.35^{abc}	82.06 ± 1.99^{bcd}	4.23 ± 0.72^{a}	5.06 ± 0.31^{a}	4.45 ± 1.35^{abc}	6.32 ± 0.01^{cd}	0.361 ± 0.01^{b}
	1.0	4.60 ± 0.30^{ab}	80.01 ± 1.99^{cd}	4.28 ± 0.49^{a}	5.07 ± 0.80^{a}	6.24 ± 1.92^{ab}	6.31 ± 0.02^{d}	0.366 ± 0.02^{b}
	1.5	4.78 ± 0.27^{a}	78.36 ± 2.45^{d}	4.55 ± 1.05^{a}	5.14 ± 0.42^{a}	7.39 ± 1.24^{a}	6.31 ± 0.02^{d}	0.400 ± 0.01^{a}

Values are mean ± standard deviation of triplicate measurements ($n = 3$). Means with different lowercase superscripts in the same column are significantly different ($p < 0.05$). CHO: carbohydrate.

in a greater reduction in moisture content in samples. The moisture content of the fish powder increased with the increasing level of MC. The hygroscopic nature of MC may be the contributing factor. Moisture content showed a positive correlation with temperature and MC with r = 0.864 and 0.462, respectively (Table 2).

The FMD fish powder samples showed a decreasing trend in crude protein at the higher drying temperature and MC concentration. However, the interaction between drying temperature and MC concentration did not have a significant effect (R^2 = 0.7998, p = 0.606) on the crude protein. The higher protein content in samples dried at 70°C could have been attributed to the dehydration of water molecules between the proteins (Kim *et al*., 2020), since fish powder at 70°C had a lower moisture content. The differences in protein content may also be due to the difference in degrees of protein denaturation at the two drying temperatures. Higher protein denaturation has been reported at higher temperatures, of about 600-fold higher for every 10°C temperature range (Lekjing *et al*., 2017). High temperature drying of fish accelerates fatty acid oxidation, and increases protein denaturation, which leads to further protein destruction in products (Kilic, 2009). Abraha *et al*. (2018) also reported that drying at lower temperature has a greater negative effect on the protein content than at a higher temperature. The effect of increasing drying temperature on the decrease in crude protein content was also observed by Ajifolokun *et al*. (2018) in dried shrimp powder at 50, 60, and 70°C. The increase in MC also contributed to the higher carbohydrate content, thus lowering the protein content of the fish powder. Samples dried without MC addition at 70°C had the highest value of crude protein content (86.72%). Temperature and MC exhibited a negative relationship with the crude protein, having a correlation coefficient of -0.661 and -0.729, respectively, as shown in Table 2.

Table 2. Pearson correlations between factors and variables of FMD Japanese threadfin bream (*Nemipterus japonicus*) powder.

Variable	**Correlation coefficient (*r*)**	
	Temperature	**Methyl cellulose**
Moisture content	0.864	0.462
Crude protein	-0.661	-0.729
Fat	-0.446	0.851
Ash	-0.541	0.708
Carbohydrate	0.677	0.708
pH	-0.955	-0.281
Water activity	0.951	0.283
Protein solubility	-0.943	0.293
Water holding capacity	-0.749	-0.380
Emulsification property	0.462	-0.839
Peroxide value	0.607	-0.688
Thiobarbituric acid reactive substance	0.830	-0.346
Free fatty acid	0.844	-0.512

There were no significant differences (p > 0.05) in ash and fat content among FMD samples. The carbohydrate content of the FMD samples ranged from 0.83 to 7.39%, and increased with the increasing amount of MC and the drying temperature. The incorporation of MC also directly contributed to the carbohydrate content of powders. The carbohydrate content of the powders also increased with the increase in drying temperature from 70 to 80°C.

pH

pH is an important indicator of fish quality since proteolytic protein degradation will increase the muscle pH. The pH of the samples decreased significantly (p < 0.05) with increasing drying temperature (Table 1). The pH showed a very strong inverse correlation with temperature (r = -0.955) and a weak inverse correlation with MC (r = -0.281). The fresh minced fish had a pH of 6.50, while the pH of fish powder dried at 70 and 80°C was in the proximity of 6.3 - 6.4. A slight pH decrease was observed with increasing concentrations of MC. Fish protein instability and increased susceptibility to lipid oxidation may occur at pH < 6.3 (Kristinsson and Liang, 2006). This pH decrease may affect the functional properties of the fish powder.

Water activity

Water activity (a_w) reflects the chemical and biological stability of the food. Reducing water activity in food prevents microbial growth (Erkmen and Bozoglu, 2016). The interaction between drying temperature and MC concentration on a_w was significant (R^2 = 0.9980, p = 0.000). The a_w of the dried fish powder was significantly increased (p < 0.05) with an increase in the MC concentrations and drying temperatures (Table 1). As shown in Table 2, there was a positive correlation between a_w and temperature (r = 0.951), and between a_w and MC (r = 0.283). The fish powder dried at 70°C had a significantly lower (p < 0.05) a_w as compared to the powder dried at 80°C, probably due to the lower moisture content of samples dried at 70°C. It was reported by Azizpour *et al*. (2016) and Hamzeh *et al*. (2019) that shrimp powder with lower moisture content had lower a_w. However, among the samples dried at 80°C, the MC concentration (0.0 - 1.0%) had no significant effect on the a_w of the powders. All samples had an a_w < 0.40, which was sufficiently low to prevent the growth of most microorganisms, hence, they are shelf stable.

Protein solubility

Protein solubility (PS), water holding capacity (WHC), and emulsification properties (EP) of fish proteins depend predominantly on the integrity of the myofibrillar protein. Protein solubility is perhaps the most important functional property because it directly affects other functional characteristics such as WHC and EP (Sun *et al*., 2017). These important functional properties of fish proteins are affected by the protein-water and protein-protein interactions, which in turn are affected by the spatial conformation of the protein (Liu *et al*., 2017). Hence, these properties are important to be evaluated in the fish powder to predict their suitability in food formulations. Protein solubility is affected by the presence of hydrophobic acid residues distributed on the protein surface (Jia *et al*., 2017). It is also affected by the pH changes, which will determine the degree of dissociation and disaggregation of the protein molecules. The increase in pH contributed to the increase in protein solubility (Dhanabalan *et al*., 2020). Statistical results indicated that only the drying temperature had a significant (p < 0.05) effect on the PS. It had an inverse correlation with the drying temperature (r = -0.943). As drying temperatures increased, the PS decreased; thus, a greater loss of PS was observed at 80°C. This can be validated by the decrease in pH with temperature as well. It was also observed that as MC concentrations increased, a concurrent increase in PS was recorded, which may denote a protective effect of MC against protein denaturation, but not statistically significant. The highest PS (32.33%) was obtained from powder dried at 70°C with 1.5% MC, and was significantly different (p < 0.05) from the sample without a foaming agent at 80°C (Table 3). Overall, the PS values obtained for FMD threadfin bream meat powder were higher than previously reported for FMD shrimp powder by Azizpour *et al*. (2016).

Water holding capacity

The WHC of the fish powder relates to the hydration property of the powder, which is affected by the degree of denaturation of the fish protein. The majority of the water in the protein is located in between myofibril filaments (Wang *et al*., 2016). The WHC was significantly (p < 0.05) affected by the drying temperature. An inverse correlation (r = -0.749) was observed between drying temperature and WHC. The highest WHC was obtained in samples without a foaming agent; however, there was no statistically significant difference among all samples (Table 3). The presence of MC may envelop the myofibrillar protein, as reported by Barbut and Mittal (1996). They stated that the addition of carboxymethyl cellulose reduced the water holding capacity of frankfurters. Overall, the WHC values of samples dried at 70°C were higher than those at 80°C. During drying, the water loss caused the proteins to aggregate and denature. The proteins then lost their three-dimensional structure, which is irreversible (Santana *et al*., 2015).

Emulsification property

The ability of proteins to form an emulsion is essential to the formation of a homogenous texture in a food system. Samples without MC addition at drying temperatures of 70 and 80°C had the highest

Table 3. Effect of drying temperatures and methyl cellulose concentrations on functional properties of FMD Japanese threadfin bream (*Nemipterus japonicus*) powder.

T (°C)	MC (%)	PS (%)	WHC (mL/g)	EP (%)
70	0.0	30.48 ± 0.64^{ab}	2.07 ± 0.90^{a}	92.08 ± 0.72^{ab}
	0.5	31.15 ± 1.79^{ab}	1.97 ± 0.49^{a}	88.33 ± 1.44^{bcd}
	1.0	31.85 ± 1.95^{ab}	1.93 ± 0.06^{a}	87.50 ± 2.50^{cd}
	1.5	32.33 ± 2.41^{a}	1.43 ± 0.12^{a}	83.92 ± 2.52^{d}
80	0.0	27.13 ± 1.25^{b}	1.60 ± 0.36^{a}	93.33 ± 0.72^{a}
	0.5	27.56 ± 2.42^{ab}	1.13 ± 0.12^{a}	90.42 ± 1.18^{abc}
	1.0	28.05 ± 1.83^{ab}	1.10 ± 0.12^{a}	90.17 ± 0.76^{abc}
	1.5	28.27 ± 1.49^{ab}	1.47 ± 0.10^{a}	88.08 ± 1.70^{bcd}

Values are mean ± standard deviation of triplicate measurements (n = 3). Means with different lowercase superscripts in the same column are significantly different (p < 0.05). PS: protein solubility; WHC: water holding capacity; EP: emulsification property.

EP. The EP was significantly affected by the drying temperature (p < 0.05) and the MC concentration (p < 0.05), but not by their interaction (p = 0.472). The EP showed a very strong inverse correlation with MC (r = -0.839) and a linear relation with drying temperature. The EP increased with the increase in the drying temperature, and decreased with the increasing concentration of the foaming agent (R^2 = 0.8154). The increase in MC concentration may lower the content of flexible peptides that can migrate to the oil-water interface, and thus the EP decreases (Gao *et al*., 2018). Although the mixture of proteins and polysaccharides is expected to combine the emulsifying role of proteins with the stabilising role of polysaccharides (Hernández-Marín *et al*., 2013), no interaction has been reported for the adsorption behaviour of some mixtures of proteins and polysaccharides (egg white protein / gum Arabic) at the oil-water interface (Patino and Pilosof, 2011). The chemical composition of the emulsion droplet surface depends on how the protein and polysaccharide molecules are adsorbed at the interface. If the surface-active of a polysaccharide has better surface properties than a protein during competitive adsorption, the combination of a polysaccharide and a protein may be advantageous. Overall, drying at 80°C produced fish powders with a higher EP.

Peroxide value

Lipid stability in the FMD fish powder was measured by the values of PV, TBARS, and FFA. Among those, PV is the most common quality indicator for fats and oils during production and storage. The reaction of oxygen with unsaturated fatty acid molecules to form hydroperoxides, measured by PV, is an important stage in oxidation, and its quantity can be used as an indicator of the degree of oxidation in the early stages (Ismail *et al*., 2016). PV measures the primary oxidation of lipid breakdown products, which are usually less stable during drying as compared to other secondary compounds. Although a slight decrease was obtained with the increase in the amount of MC used, nonetheless, there were no significant differences (p > 0.05) in PV among FMD fish powders (Figure 1). The interaction between drying temperature and MC also did not exhibit a significant influence on the PV of powders, except for the drying temperature. PV had a strong positive correlation with the drying temperature (r = 0.607), and a strong negative correlation with MC (r = -0.688). The PV results were in the range of 14 - 16 mEq/kg for all samples; thus, they were still within the acceptable PV limits of 2 - 20 mEq/kg as noted by Selim *et al*. (2021).

Thiobarbituric acid reactive substances

Fish meat is sensitive to oxidation due to the abundant polyunsaturated fatty acids (PUFA). The oxidation could be accelerated by mincing, which increases the exposed surface area of the fish meat to oxygen during the drying and heating processes. Therefore, FMD fish powder may be prone to this

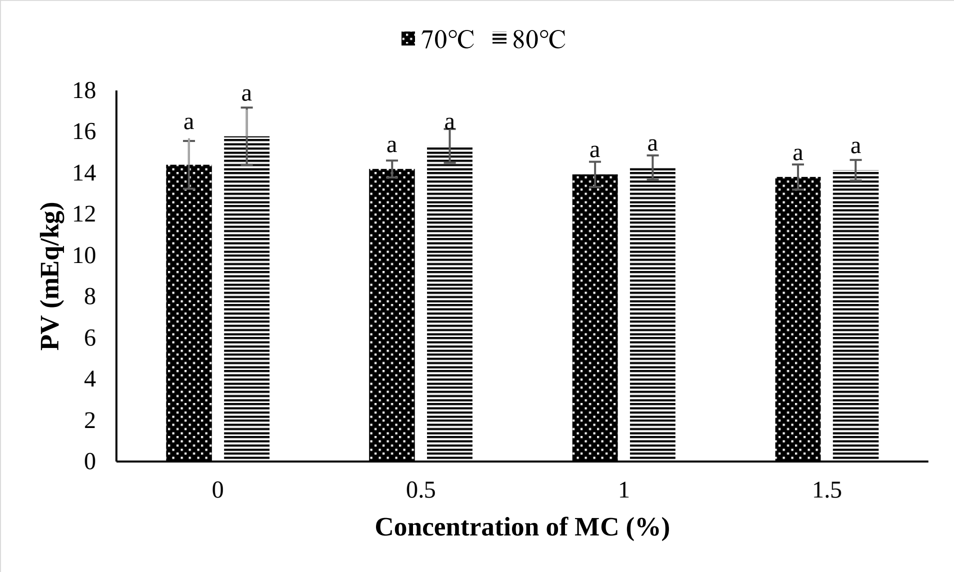

Figure 1. Effect of drying temperatures and methyl cellulose concentrations on peroxide value (PV) of oil extracted from FMD Japanese threadfin bream (*Nemipterus japonicus*) powder.

form of oxidation due to the mincing step involved during the preparation stage prior to drying. The TBARS (Figure 2) were affected by the drying temperature ($p < 0.05$) and MC concentration, but not their interaction ($R^2 = 0.7736$, $p = 0.230$). A very strong positive correlation ($r = 0.830$) was found between TBARS and temperature (Table 2). The TBARS of fish powders dried at 70°C were significantly lower ($p < 0.05$) than those of fish powder dried at 80°C. The higher TBARS for samples dried at 80°C could be attributed to the higher rate of autoxidation of unsaturated fatty acids. The TBARS values for all samples (7.64 - 9.00 µmol MDA/kg) were still within the acceptable range. TBARS values less than 9 µmol MDA/kg fish were proposed to not impart a rancid taste (Ke *et al.*, 1984). For both drying temperatures, samples without MC addition had the highest TBARS values.

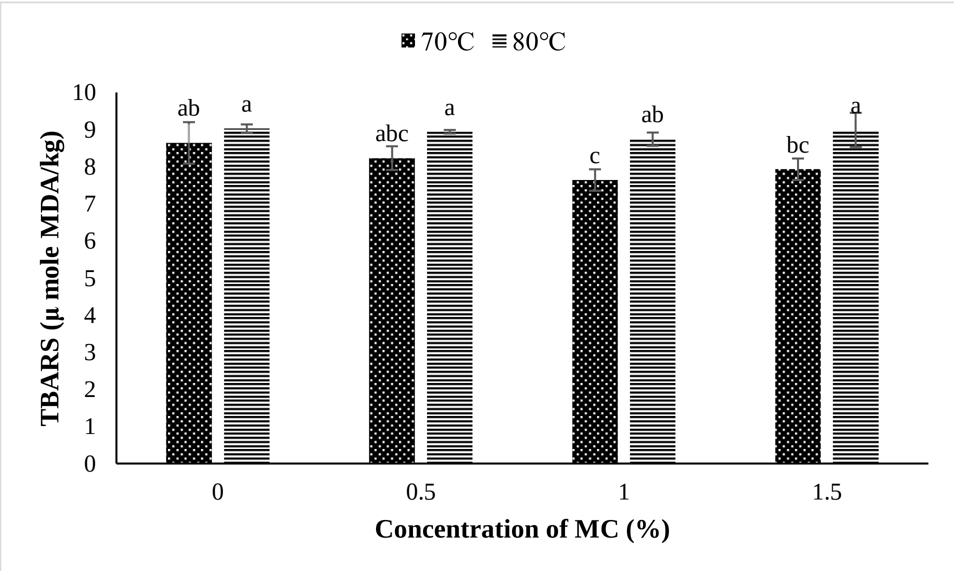

Figure 2. Effect of drying temperatures and methyl cellulose concentrations on thiobarbituric acid reactive substances (TBARS) of FMD Japanese threadfin bream (*Nemipterus japonicus*) powder.

Free fatty acid

Fish muscles are prone to lipolysis and oxidation due to the high activity of the autolytic enzymes, which mainly result in the accumulation of FFA. The presence of FFA has an adverse effect on protein solubility and relative viscosity, which are associated with the textural degradation of the muscle (Aubourg, 2001). Fish powder dried at 70°C had significantly lower ($p < 0.05$) FFA as compared to powder dried at 80°C (Figure 3). The triglycerides and phospholipids present in fish muscle are partially hydrolysed due to the action of thermolysis, since higher temperatures increase the rate of the hydrolysis reaction. The FFA contents showed a decreasing trend with the increase in MC concentration. Samples without MC addition had significantly higher ($p < 0.05$) FFA than other samples containing 1.0 and 1.5% MC. The FFA for all the fish powders was below the maximum limit of 7%. In crude fish oil, the allowable range is 1 - 7% (Deepika *et al.*, 2014). The formation of FFA is the main factor that raises the acid value in dried fish. These FFAs are further oxidised, and secondary oxidation products developed, leading to the production of off flavours and odours in fish and fishery products, and textural changes (Gokoglu *et al.*, 2012).

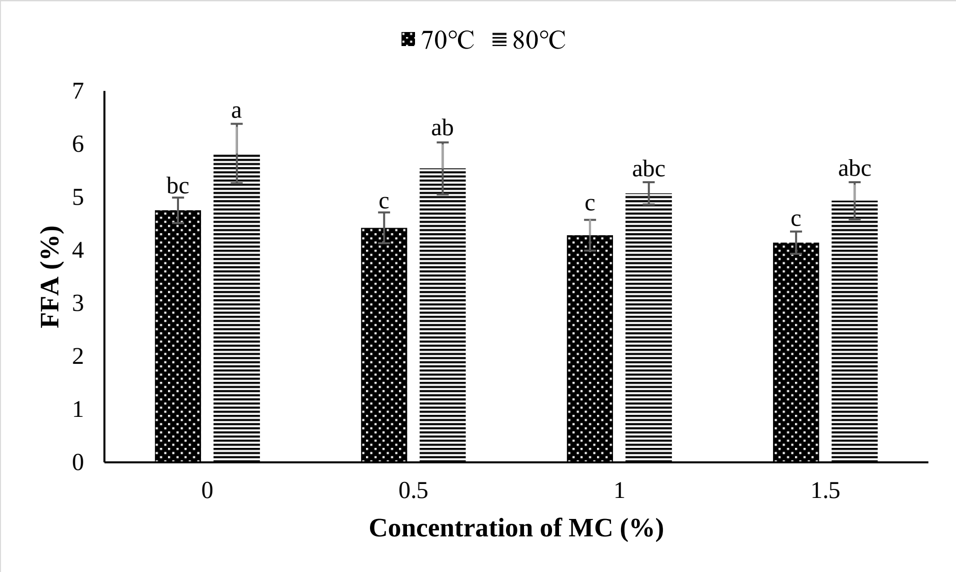

Figure 3. Effect of drying temperatures and methyl cellulose concentrations on free fatty acid (FFA) of oil extracted from FMD Japanese threadfin bream (*Nemipterus japonicus*) powder.

Conclusion

The present work demonstrated the feasibility of foam-mat drying to produce fish powders that are acceptable to be used as an ingredient in relevant food formulations. A moisture content of below 5.0% (db) was achieved upon drying at 70 and 80°C for 450 and 270 min, respectively. However, better properties were obtained in FMD fish powder dried at 70°C. Both drying temperatures of 70 and 80°C were able to produce high protein fish powders (78.36 - 86.72%) with low a_w (< 0.4) which indicated that the powders were fairly stable against microbial spoilage. The functional properties of the fish powder were most affected by the drying temperature. The PV, TBARS, and FFA increased with drying temperature; however, they were still within acceptable ranges. Overall, FMD fish powder at 70°C showed better properties, with 0.5% MC being the best among them. Hence, further work on MC in combination with other foaming agents at different drying temperature ranges should be explored.

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