



Nutritional composition and total collagen content of three commercially important edible jellyfish



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ABSTRACT

The study aimed to evaluate nutraceutical potential of three commercially significant edible jellyfish species (*Acromitus hardenbergi*, *Rhopilema hispidum* and *Rhopilema esculentum*). The bell and oral arms of these jellyfishes were analyzed for their proximate composition, calorific value, collagen content, amino acid profile, chemical score and elemental constituent. In general, all jellyfish possessed low calorific values (1.0–4.9 kcal/g D.W.) and negligible fat contents (0.4–1.8 g/100 g D.W.), while protein (20.0–53.9 g/100 g D.W.) and minerals (15.9–57.2 g/100 g D.W.) were found to be the richest components. Total collagen content of edible jellyfish varied from 122.64 to 693.92 mg/g D.W., accounting for approximately half its total protein content. The dominant amino acids in both bell and oral arms of all jellyfish studied includes glycine, glutamate, threonine, proline, aspartate and arginine, while the major elements were sodium, potassium, chlorine, magnesium, sulfur, zinc and silicon. Among the jellyfish, *A. hardenbergi* exhibited significantly higher total amino acids, chemical scores and collagen content ($p < 0.05$) compared to *R. hispidum* and *R. esculentum*. Having good protein quality and low calories, edible jellyfish is an appealing source of nutritive ingredients for the development of oral formulations, nutraceuticals and functional food.

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1. Introduction

Jellyfish (Cnidaria: Scyphozoa: Rhizostomeae) have always been an important fishery commodity and a multi-million business in the world (Nishikawa, Thu, Ha, & Thu, 2008; Nishikawa et al., 2009). In 2009, China alone was reported to produce 62,969 tonnes of jellyfish, a 34% increase from the previous year, creating revenue of about 149 million USD, which was also 33% increase from the year before (FAO, 2011). Jellyfish fishing is widely practised in China, Japan, Malaysia, Indonesia, Thailand, Vietnam and the Philippines. Usually when the annual monsoon hits the coast, jellyfish fishing would be a source of bonus income for fishermen where they would shift their attention to catching this seasonal

seafood speciality which would fetch them a relatively rewarding price. Acknowledging the increasing demand of this exotic delicacy, development for mass culture systems of jellyfish are being vigorously researched (Pierce, 2005; Raskoff, Sommer, Hamner, & Cross, 2003). Jellyfish in China has grown to such magnitude that they are regarded as an important pond-cultured species which had replaced shrimp and fish aquaculture in certain areas (You et al., 2007).

Jellyfish fishery in Malaysia is a century-old industry that has been carried on for at least three generations. Perhaps the most unique characteristic of jellyfish fisheries in Peninsular Malaysia is the year round availability of certain jellyfish species which is a most unusual phenomenon worldwide. Jellyfish abundance are seasonal in nature in many parts of the world. Four major edible jellyfish species in Malaysia include the river jellyfish, *Acromitus hardenbergi* Stiasny, 1934; the red jellyfish, *Rhopilema esculentum* Kishinouye, 1891; the sand jellyfish *Rhopilema hispidum* Vanhöffen, 1888; and the white jellyfish, *Lobonema smithii* Mayer, 1910 (Yusoff, Nishikawa, & Kuppan, 2010). Among those jellyfish species, the former three are commercially active, especially *A. hardenbergi* and *R. hispidum* which are most commonly available

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throughout the year. Local fishermen have been attributing the cure of joint problems as well as the prevention of aging and fatigue to the consumption of jellyfish. Research has proven that jellyfish is rich in antioxidants (Ding et al., 2011; Yu et al., 2006) exhibiting anti-hypertensive and anti-hyperlipidemic (Liu, Zhang, Zhang, & Liu, 2012); UV-protective (Zhuang, Hou, Zhao, Zhang, & Li, 2009); and immunostimulating activity (Sugahara et al., 2006). Besides, Hsieh (2005) reported that oral consumption of collagen obtained from cannonball jellyfish (*Stomolophus meleagris*) attenuated the onset and progression of arthritis in murine model. The consumption of edible jellyfish takes deep roots in the culture of the Asian Pacific region and steadily spreading far and wide.

Despite lofty economical and pro-health values, edible jellyfish are poorly characterized along with reports on their nutritional qualities. Lack of information on jellyfish, especially nutritional quality of edible jellyfish, not only limits innovations and applications of jellyfish but also restricts economical potentials of this commodity to generate larger profits. Therefore, the present study aimed to evaluate nutritional characteristics and estimate total collagen contents of three commercially important edible jellyfish. The maintenance of food and nutritional security have never been more important, given increasing environmental and resource depletion. Novel, innovative and sustainable sources of food which are high in nutritional value, as well as readily available, are widely sought after nowadays. Findings from this study would serve as milestone towards the utilization of jellyfish as food ingredients as well as its quality control. This study illustrated that jellyfish can be a valuable natural source of an important commodity with high commercial potential such as high quality collagen.

2. Materials and methods

2.1. Jellyfish samples

Jellyfish samples were collected once every month from the fishing grounds in Bagan Datoh, Perak and Kukup Johor from

Nov. 2009 to Nov. 2010. The river jellyfish, *A. hardenbergi* and the red jellyfish, *R. esculentum* were obtained from Bagan Datoh, Perak while the sand jellyfish, *R. hispidum* from Kukup, Johor (Fig. 1). Generally, edible jellyfish have two distinct body parts i.e. the bell and the oral arms. Mimicking the common processing practice of jellyfish fishermen, freshly caught jellyfish were excised into bell and oral arms and immediately transported back to the laboratory on ice. In the laboratory, jellyfish samples were cleansed thoroughly with distilled water and lyophilized. Lyophilized samples were pulverized into homogeneous powder and kept at -20°C prior to analyses.

2.2. Proximate analyses

All analyses were performed according to the methods of AOAC, 2005. Moisture, crude protein, crude fat and ash contents were determined using AOAC Official Method 934.01 (oven drying), 976.05 (automated Kjeldahl method), 948.15 (Mojonnier acid hydrolysis method) and 938.08 (furnace combustion), respectively. Conversion factor of 5.8 was used for the determination of total crude protein of jellyfish (Doyle, Houghton, McDevitt, Davenport, & Hays, 2007). Total carbohydrate was calculated by difference $[100 - (\text{moisture} + \text{protein} + \text{fat} + \text{ash})]$.

2.3. Energy content

Gross calorific content was determined using a benchtop isoperibol calorimeter (LECO AC-350, USA) and expressed as kcal/g D.W. Calculated gross calorific content was performed using energy conversion factors according to FAO (2003).

2.4. Color

Color measurements were performed in triplicates using Chroma Meter CR-300 (Minolta, Japan) and reported as Hunter *L*, *a*, *b* values.

2.5. Amino acid analysis

2.5.1. HPLC–DAD

Amino acid content was analyzed using a HPLC gradient system with precolumn phenyl isothiocyanate (PITC) derivatization. Before derivatization, lyophilized samples were hydrolyzed using 6 N HCl containing 0.01% (w/v) phenol for 24 h at 110°C under vacuum. Hydrolysis of sample for tryptophan analysis was performed using 4 N NaOH. Hydrolyzed samples and amino acid standards (Sigma Aldrich, MO, USA) were filtered upon addition of α -amino-N-butyric acid (AABA) as internal standard and vacuum dried. The residue was dissolved completely in coupling reagent consisting of methanol-water-triethylamine (2:2:1, v/v/v) and dried under vacuum. This is followed by the reaction with derivatization reagent consisting of methanol-PITC-triethylamine-water (7:1:1:1, v/v/v/v) at room temperature for 20 min prior to drying under vacuum to remove PITC.

Derivatized samples were redissolved in 0.1 M ammonium acetate, pH 6.5 and filtered through a $0.2\ \mu\text{m}$ nylon filter before being injected into an Agilent 1100 HPLC system equipped with a quaternary pump, photodiode array detector (DAD) and autosampler (Agilent Technologies, USA). A ZORBAX Eclipse Plus C18 Column ($2.1 \times 150\ \text{mm}$, $3.5\ \mu\text{m}$, Agilent Technologies, USA) was used for separation using a binary gradient generated by Buffer A (0.1 M ammonium acetate, pH 6.5) and Buffer B (0.1 M ammonium acetate-acetonitrile-methanol, 44:46:10, v/v/v, pH 6.5). The flow-rate was kept constant at 1.0 ml/min and the column was maintained at 43°C . The gradient was established starting with 0% eluent B and continued to 10% at 15 min, 40% at

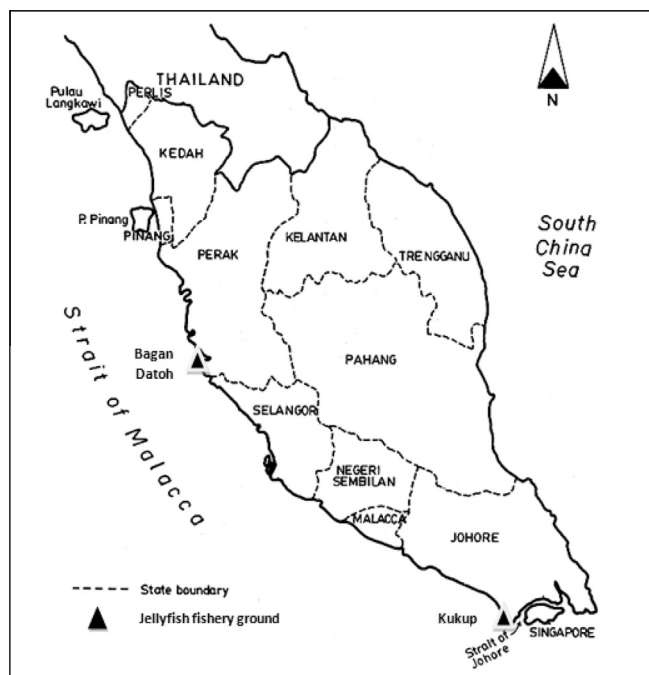


Fig. 1. Location of jellyfish fishery grounds where jellyfish were sampled and collected in Peninsular Malaysia. *Acromitus hardenbergi* and *Rhopilema esculentum* were collected at Bagan Datoh, Perak ($03^{\circ} 59' \text{N}$ $100^{\circ} 46' \text{E}$), whereas *Rhopilema hispidum* was collected at Kukup, Johor ($01^{\circ} 19' \text{N}$ $103^{\circ} 27' \text{E}$).

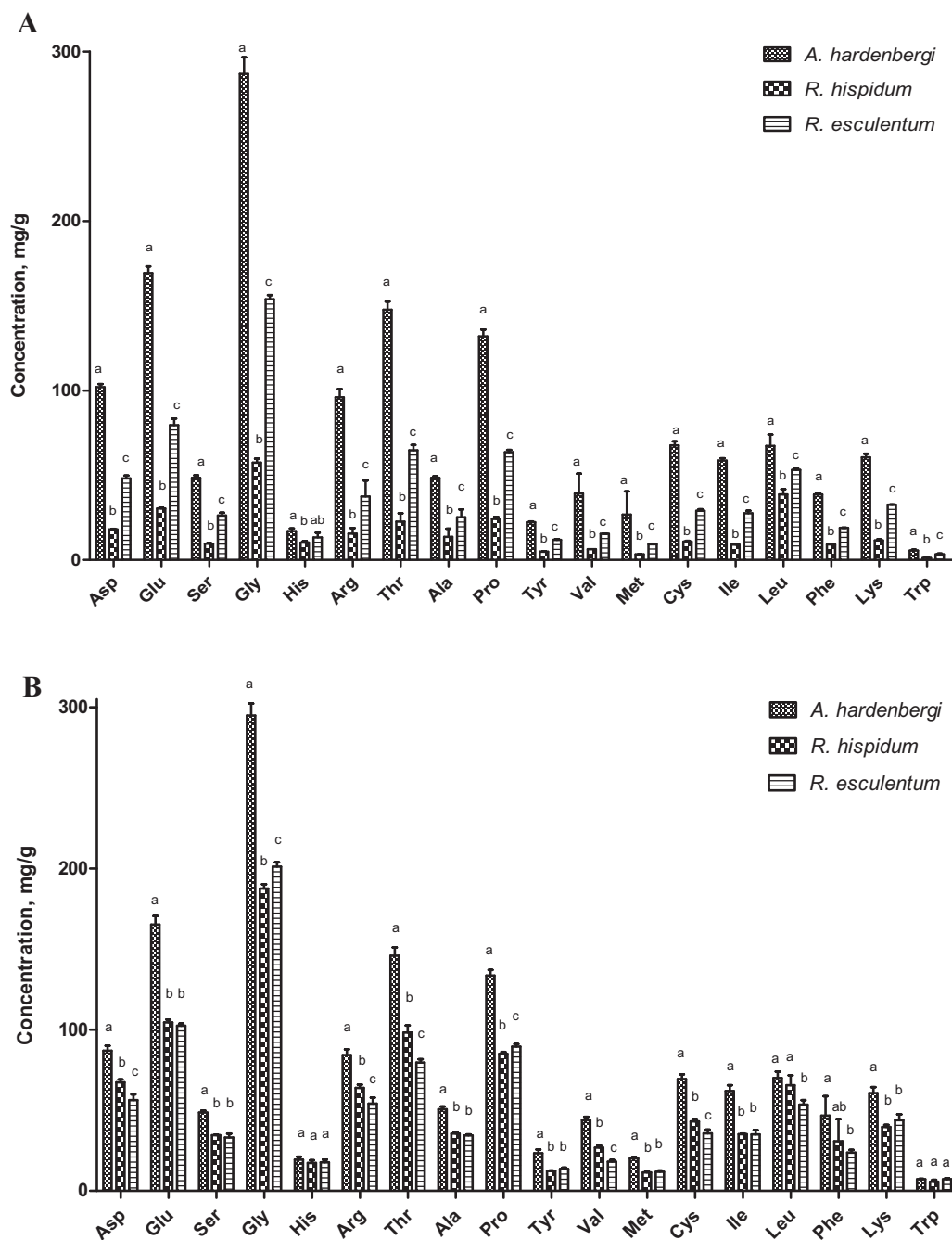


Fig. 2. Amino acids composition (mg/g dry weight) of different body parts: (A) bell and (B) oral arms of various edible jellyfish. Data are represented as the mean $\pm$ SD (One-way ANOVA followed by Tukey *post hoc* test). Groups with different letters (a–c) are significant, $p < 0.05$; $n = 3$.

30 min, 50% at 40 min and was kept at 100% for 5 min after 50 min and within 3 min the gradient was switched to 100% Buffer A. The absorbance at 254 nm was used for calculations. Each standard and sample was analyzed for at least 3 runs. The chromatographic system and analysis of chromatograms were controlled and performed with the Chemstation software Rev. 08.01 (Agilent Technologies USA).

2.5.2. Chemical score

Pattern of essential amino acid requirements established by [FAO/WHO/UNU., 1985](#) was used as reference to assess chemical scores and predict first-limiting amino acids of jellyfish proteins. Calculation of chemical score was carried out by calculating the

amino acid score for each essential amino acid according to the formula as follows;

$$\text{Amino acid score} = \frac{\text{mg of amino acid per gram of test protein}}{\text{mg of amino acid in reference pattern}} \times 100$$

The lowest amino acid score represented the chemical score of the test protein and is used to predict the first-limiting amino acid.

2.6. Total collagen content

Total collagen content was estimated by hydroxyproline analysis. Total hydroxyproline content was determined after acid

hydrolysis of samples using 6 M HCl for 6 h at 105 °C, with a hydroxyproline colorimetric assay kit (BioVision, BioVision Inc, CA, USA) according to the manufacturers instructions. The assay involved a convenient method which resulted in a chromogen with an absorbance maximum at 560 nm and was sensitive over the range of 0.1–2 µg.

Total collagen content of samples in g/100 g dry weight was estimated as follows;

$$\text{Total collagen content (\%DW)} = H \times CF$$

where,

H = total hydroxyproline content (g/100 g dry weight)

CF = conversion factor. The general conversion factor for hydroxyproline to collagen is 8.

Meanwhile, ratio of total collagen as proportion to total protein content was estimated as follows:

Total collagen (protein basis) (%)

$$= \frac{\text{Estimated collagen content}}{\text{Total protein content (amino acid basis)}} \times 100$$

where,

Estimated collagen content (mg/g) = Hyp content (mg/g) × 8

Total protein content (amino acid basis) = Total amino acid content (including Hyp) (mg/g)

2.7. Energy dispersive X-ray (EDX)

Elemental contents of lyophilized jellyfish were determined using energy dispersive X-ray spectrometer (EDX) with QBSD signal attached to a scanning electron microscope (SEM-EDX, JEOL, JSM 6400, Japan). Quantitative estimates of elemental composition (Weight%) were determined using Oxford Instruments INCA software package, INCA Energy, 2000.

2.8. Statistical analysis

The significant differences of the mean values were analyzed by ANOVA followed by Tukey HSD *posthoc* test at 95% confidence level using Minitab Statistical Analysis Software (Minitab Inc., State College, PA, USA). All analyses were performed independently ($n \leq 3$) and all data were presented as mean value ± standard deviation.

3. Results and discussion

3.1. Proximate composition and physical characteristics

On the whole, edible jellyfish were found to be rich in protein and minerals (ash content) (Table 1). The uniqueness of jellyfish tissues includes their high capability in water holding. It was found that water comprised 95–98 g/100 g wet weight (W.W.) of the jellyfish studied and a hygroscopic 12–20% g/100 g of their dry weight (D.W.). Although soft-bodied invertebrates commonly contain a high content of water, the moisture content of jellyfish were found to be higher than those reported in volador, pota and octopus (78.54–82.62% W.W.) (Ruiz-Capillas, Moral, Morales, & Montero, 2003) as well as cuttlefish and squid (78.3–81.2% W.W.) (Zlatanov, Laskaridis, Feist, & Sagredos, 2006).

The trend of proximate composition of all analyzed edible jellyfish was found to be total ash > protein > water > carbohydrate > lipid in the bell while in the oral arms the trend was found to be total protein > ash > water > carbohydrate > lipid. It was observed that the distribution of protein and ash content of jellyfish differed significantly ($p < 0.05$) in different body parts irrespective of species. It was found that jellyfish oral arms have

approximately twice the protein content than the bells. Between species, the red jellyfish, *R. esculentum*, was found to possess significantly higher ($p < 0.05$) protein content than the river jellyfish, *A. hardenbergeri* and the sand jellyfish, *R. hispidum*. On the other hand, ash content of the three jellyfish studied was found to vary inversely to the protein content, where *R. hispidum* bell and oral arms were observed to contain the highest ($p < 0.05$) ash content, while *R. esculentum* the least ($p < 0.05$) among all the species. Ash content was found to be significantly higher ($p < 0.05$) in the jellyfish bells compared to the oral arms. Inferentially, the bell of jellyfish is majorly responsible for the floating capacity of the organisms, thus its high content of minerals which are remnants of the buffering activities of the organism to maintain osmotic balance. Meanwhile, the oral arms contribute to the movements of jellyfish, resulting in relatively higher density of muscle cells. The present study also demonstrated the inverse relationship between water and lipid content of invertebrate tissues. Lipid content was almost non-detectable (<0.01%) (Table 1). The need of hydrolysis for the detection of the minute amount of lipid suggested the possibility of bound fat being dominant within jellyfish tissues as compared to free fat. Lipid content was found to be significantly higher ($p < 0.05$) in the oral arms of the jellyfish than the bells. Protein and ash were also reported to be the major nutritional components in *Stomolophus meleagris*, *Cotylorhiza tuberculata* and *Rhizostoma pulmo* jellyfish, while omega-3 and -6 polyunsaturated fatty acids were found to present in higher level in zooxanthellate jellyfish (Hsieh, Leong, & Rudloe, 2001; Leone, Lecci, Durante, Meli, & Piraino, 2015). The proximate content of jellyfish tissues were highly influenced by the water bodies where these invertebrates were found.

Color-wise, the oral arms were found to be darker than the bells in all jellyfish studied. Fresh *A. hardenbergeri* is pinkish in appearance, where the oral arms have a darker red color; *R. hispidum* is white in whole while *R. esculentum* has whitish bell and dark red oral arms. Upon lyophilisation, Hunter color values (L , a , b) were found to be significantly different ($p < 0.05$) between types of jellyfish as well as their body parts (Table 1). Lyophilization of jellyfish tissues was necessary to preserve the color and nutritional quality of the tissues. In a preliminary study, jellyfish samples dried in oven at 50–60 °C all turned brown and the texture hardened to crisps.

3.2. Energy density

The study found that edible jellyfish were a source of food with very low calorific values (Table 1). The gross energy content of all jellyfish studied ranged from 980–2823 kcal/kg D.W. The gross energy contents obtained using bomb calorimetry for the river jellyfish, *A. hardenbergeri* (bell: 1663.6 kcal/kg; oral arms: 2403.0 kcal/kg), sand jellyfish, *R. hispidum* (bell: 975.2 kcal/kg; oral arms: 2004.3 kcal/kg) and red jellyfish, *R. esculentum* (bell: 2113.6 kcal/kg; oral arms: 2823.13 kcal/kg) were found to be highly analogous to the calculated ones. Calculated metabolizable energy content for the bell of the river jellyfish, sand jellyfish and red jellyfish were found to be 1595.6 ± 41.9 kcal/kg, 1194.2 ± 33.8 kcal/kg and 2005.9 ± 28.7 kcal/kg respectively while the oral arms of the jellyfish exhibited 2172.5 ± 34.7 kcal/kg, 2115.92 ± 17.3 kcal/kg and 2624.20 ± 33.8 respectively. Comparatively, jellyfish oral arms were found to have significantly higher ($p < 0.05$) energy density than the bells. Among the species, energy density of *R. esculentum* was found to be significantly higher ($p < 0.05$) than *A. hardenbergeri* and *R. hispidum*. Previously, Doyle et al. (2007) also reported differences in energy density among different jellyfish species and between different tissues (body parts) of the same jellyfish species. Jellyfish are reported to contain very low amount of cholesterol (Hsieh & Rudloe, 1994). Eventually, all

Table 1

Proximate composition (g/100 g), energy content and colour of bell and oral arms from different edible jellyfish.

Composition	Bell			Oral arms		
	<i>A. hardenbergi</i>	<i>R. hispidum</i>	<i>R. esculentum</i>	<i>A. hardenbergi</i>	<i>R. hispidum</i>	<i>R. esculentum</i>
<i>Of wet mass</i>						
Moisture	98.40 ± 0.56 ^a	97.80 ± 0.36 ^a	96.02 ± 1.44 ^a	97.93 ± 0.64 ^a	96.14 ± 1.02 ^a	95.54 ± 1.75 ^a
Crude protein ¹	0.84 ± 1.21 ^a	0.50 ± 0.23 ^a	1.58 ± 0.78 ^a	1.26 ± 1.05 ^a	2.01 ± 1.64 ^a	2.75 ± 0.88 ^a
Ash	1.32 ± 0.25 ^a	1.56 ± 0.56 ^a	1.30 ± 0.45 ^a	1.30 ± 0.56 ^a	1.35 ± 0.58 ^a	0.89 ± 0.53 ^a
<i>Of dry mass</i>						
Moisture	12.17 ± 0.59 ^a	13.57 ± 0.15 ^b	17.40 ± 0.20 ^c	15.93 ± 0.61 ^a	13.03 ± 0.25 ^b	20.73 ± 0.57 ^c
Crude protein ¹	21.38 ± 0.32 ^a	19.95 ± 0.71 ^a	38.12 ± 1.07 ^b	33.69 ± 1.12 ^a	43.80 ± 1.25 ^b	53.87 ± 2.11 ^c
Crude lipid	0.38 ± 0.16 ^a	0.46 ± 0.28 ^a	0.61 ± 0.06 ^a	1.08 ± 0.20 ^a	1.37 ± 0.17 ^{ab}	1.79 ± 0.26 ^b
Ash	48.42 ± 0.27 ^a	57.15 ± 0.51 ^b	33.22 ± 0.53 ^c	31.10 ± 1.54 ^b	35.78 ± 0.25 ^b	15.90 ± 0.47 ^c
Carbohydrate ²	17.66	18.20	8.87	6.02	10.65	7.7
Calculated energy content, kcal/kg	1595.58 ± 41.91 ^a	1194.15 ± 33.84 ^b	2005.88 ± 28.71 ^c	2172.52 ± 34.70 ^a	2115.92 ± 17.29 ^a	2624.20 ± 33.75 ^b
Gross energy content, kcal/kg	1663.60 ± 47.47 ^a	975.23 ± 34.65 ^b	2113.57 ± 65.12 ^c	2403.00 ± 42.12 ^a	2004.33 ± 17.14 ^b	2823.13 ± 30.09 ^c
Instrumental colour	<i>L</i>	72.29 ± 3.65 ^a	66.68 ± 0.43 ^b	53.35 ± 1.03 ^a	68.95 ± 2.94 ^b	41.72 ± 0.50 ^c
	<i>a</i>	+1.57 ± 0.09 ^a	+0.90 ± 0.32 ^b	+5.29 ± 0.10 ^c	-0.15 ± 0.14	+6.87 ± 0.24 ^c
	<i>b</i>	+12.14 ± 0.39 ^a	+11.66 ± 0.90 ^a	+13.78 ± 0.25 ^b	+12.66 ± 0.15 ^a	+17.28 ± 0.41 ^c

a–d: Results are obtained from means of three determinations ± standard deviation. Different alphabet within the same row of the same group indicates significant difference ($p < 0.05$).

¹ Crude protein = %N × 5.80 (Doyle, Houghton, McDevitt, Davenport, & Hays, 2007).

² Carbohydrate = 100% – % (moisture + protein + fat + ash).

edible jellyfish studied were found to contain very low level of calories but high in proteins.

3.3. Amino acid profile

Generally, edible jellyfish were found to contain low essential amino acids. Glycine, glutamate, aspartate, threonine and proline were found to be the major amino acids of the jellyfish regardless of body parts (Fig. 2). As a whole, it was observed that *A. hardenbergi* exhibited significantly higher ($p < 0.05$) total amino acids content than *R. esculentum* and *R. hispidum* for both bell and oral arms. The total amino acid contents between the bell (1434.05 mg/g) and oral arms (1433.45 mg/g) of *A. hardenbergi* showed no significant difference ($p > 0.05$). On the other hand, both jellyfish from the *Rhopilema* genus showed significantly higher total amino acids content in the oral arms (RH: 965.36 mg/g; RE: 911.85 mg/g) compared to their bells (RH: 296.40 mg/g; RE: 712.96 mg/g) ($p < 0.05$). Among the jellyfish studied, the relatively high total amino acid content from the relatively low protein *A. hardenbergi*, and the relatively low amino acid content from the relatively high protein *Rhopilema* spp. may indicate high amount of non-protein nitrogenous substances in jellyfish of the genus *Rhopilema*. Jellyfish have been reported to be rich in unique amino acids such as γ -polyglutamic acid (γ -PGA) and polylysine (Herman, 2013).

Between species, especially the bells, the amino acid composition of *A. hardenbergi* was found to be significantly different from that of *Rhopilema* spp. ($p < 0.05$). There was no significant difference ($p > 0.05$) between the amino acid composition of *R. hispidum* and *R. esculentum*. Although the amount of amino acid content differed significantly from each other (especially total amino acid contents), the ratios of essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, valine and tryptophan), conditionally essential amino acids (arginine, cysteine, tyrosine, glycine, proline and serine) and non-essential acids (alanine, glutamic acid and aspartic acid) of all jellyfish were found to be similar. Regardless of body parts, all jellyfish contained approximately 33% of essential amino acids, 46% of conditionally essential amino acids and 21% non-essential amino acids. While the findings of this study agreed with the previous claims of Hsieh et al. (2001) where the proportion of essential amino acids was relatively low, the current study detected 0.12–0.55% (w/w)

tryptophan in the bells and 0.56–0.73% (w/w) in the oral arms of the jellyfish. Besides, jellyfish protein was rich in conditionally essential amino acids, which are useful to be supplemented exogenously to people of the under-developed and developing countries who are suffering amino acids malnutrition.

3.4. Chemical score

Chemical score is a common index used to evaluate protein quality of a food sample. Table 2 represents the chemicals scores and first-limiting amino acids for different jellyfish body parts. In general, the chemical scores for oral arm proteins were higher than its bell counterpart, while both proteins obtained from *A. hardenbergi* possessed the highest chemical scores (56 and 72 scores for bell and oral arm, respectively) as compared to other jellyfish species. Besides, results in Table 2 also shows that chemical scores for all tested jellyfish proteins in this study are greatly higher than proteins extracted from other jellyfish species, i.e. *Chrysaora* sp., *Aurelia* sp., *C. tuberculata* and *R. pulmo* (Barzideh, Abd. Latiff, Gan, Benjakul, & Abd. Karim, 2014; Leone et al., 2015; Nagai et al., 1999). These jellyfish proteins were graded with zero chemical score (0) due to the deficiency of tryptophan (Trp). Leone et al. (2015) found that Trp was absent from three jellyfish species in the Mediterranean Sea. Tryptophan, an essential amino acid, which functions as the biochemical precursor for several physiologically important compounds, such as serotonin and niacin, is the most common first-limiting amino acid in all the previously reported jellyfish proteins (Barzideh, Abd. Latiff, Gan, Benjakul & Abd. Karim, 2014; Kimura, Miura, & Park, 1983; Leone et al., 2015; Nagai et al., 1999). Regularly, animal proteins contain 1–2% of tryptophan, except for histones and collagen, which have none (Velisek, 2014). The relatively high level of tryptophan substantially enhanced the quality of *A. hardenbergi* proteins in term of essentiality and thus making *A. hardenbergi* proteins much superior, nutritionally, to the other jellyfish studied.

3.5. Total hydroxyproline and collagen content

So far, analysis of hydroxyproline (Hyp) is the best approach for collagen estimation. Total Hyp contents of the edible jellyfish were found to be in a significant decreasing order of *A. hardenbergi* > *R. esculentum* > *R. hispidum* ($p < 0.05$), regardless of body parts.

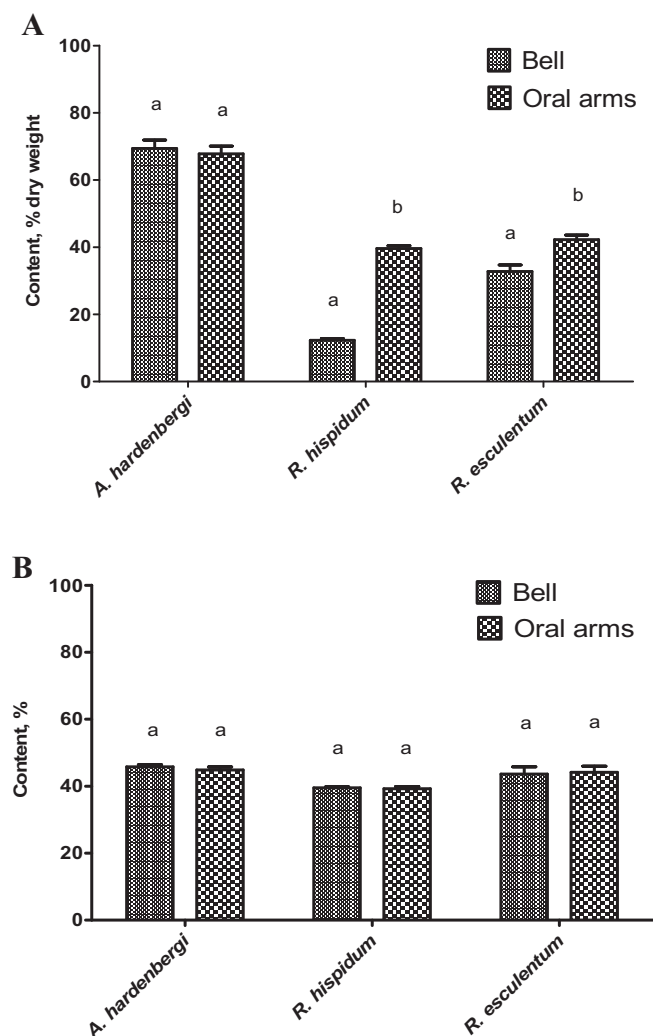


Fig. 3. Estimated collagen content of various edible jellyfish (A) Estimated total collagen content (g/100 g dry weight); (B) Estimated proportion of collagen to total protein content (g/100 g) of different body parts of jellyfish. Data are represented as the mean $\pm$ SD (Student *t* test or one way ANOVA followed by Tukey *post hoc* test). Groups with different letters (a–b) are significant, $p < 0.05$; $n = 3$.

Alike total amino acids content, no significant difference ($p > 0.05$) was observed between the Hyp content of the bell (86.74 mg/g) and oral arms (84.71 mg/g) of *A. hardenbergi*. However, both the oral arms of *R. hispidum* (49.52 mg/g) and *R. esculentum* (52.80 mg/g) were found to contain significantly higher ($p < 0.05$) Hyp content than their bells (*R. hispidum*: 15.33 mg/g & *R. esculentum*: 40.95 mg/g). It was found that lyophilized jellyfish, especially *A. hardenbergi* have comparable Hyp content to collagen extracted from the skin (77 mg/g) and bone (68 mg/g) of bigeye snapper (Kittiphattanabawon, Benjakul, Visessanguan, Nagai, & Tanaka, 2005).

The conversion factor used to convert Hyp content for the estimation of total collagen content in this study was 8 as collagen has been reported to contain 12.5%–13.5% Hyp, depending on the conversion factor used in the conversion of nitrogen content to protein (Ignat'eva, Danilov, Averkiev, Obrezkova, & Lunin, 2007; Kolar, 1990; Mazorra-Manzano, Torres-Llanez, González-Córdova, & Vallejo-Córdova, 2012). Previously, animal skins e.g. fish which contained high protein applied the conversion factor of 7.5 or 7.7 (bigeye snapper skin) (Kittiphattanabawon et al., 2005); 13.5 (murine lungs) (Kliment, Englert, Crum, & Oury, 2011) and in some cases 14.7 (Baltic cod) (Sadowska, Kołodziejewska, & Niecikowska, 2003) for the estimation of collagen based on Hyp content. By

Table 2

Chemical scores and first-limiting amino acids of different parts of various edible jellyfish.

Edible jellyfish	Body parts	Chemical score	First-limiting amino acids
<i>Acromitus hardenbergi</i>	Bell	56	Tryptophan
	Oral arms	72	Tryptophan
<i>Rhopilema hispidum</i>	Bell	12	Tryptophan
	Oral arms	54	Valine
<i>Rhopilema esculentum</i>	Bell	31	Valine
	Oral arms	36	Valine
<i>Stomolophus meleagris</i> ¹	Bell (Collagen)	0	Tryptophan
<i>Chrysaora</i> sp. ²	Bell (Collagen)	0	Tryptophan
<i>Aurelia</i> sp. ³	Whole	0	Tryptophan, Leucine
<i>Cotylorhiza tuberculata</i> ³	Whole	0	Tryptophan
<i>Rhizostoma pulmo</i> ³	Whole	0	Tryptophan

¹ Nagai et al. (1999).

² Barzideh, Abd. Latiff, Gan, Benjakul and Abd. Karim (2014).

³ Leone, Lecci, Durante, Meli, and Piraino (2015).

and large, the trend of estimated total collagen of the three jellyfish was the same as the Hyp content (Fig. 3a). The river jellyfish, *A. hardenbergi* was found to contain the highest amount of collagen among the three species studied where the total collagen content in the bell and oral arms ranged from 670 mg/g to 690 mg/g dry weight. On the other hand, collagen was found to be significantly more concentrated in the oral arms of *R. hispidum* and *R. esculentum* than the bells ($p < 0.05$). Information on the Hyp content and total collagen content of jellyfish has been limited.

Although the collagen content of jellyfish was found to vary among different body parts and between jellyfish species, no significant differences ($p > 0.05$) were detected in terms of collagen proportion to the total protein content (collagen content/crude protein) among different jellyfish species and among tissues of the same species (Fig. 3b). In general, collagen was found to be the major protein of jellyfish irrespective of jellyfish species and body parts, even though the actual amount of collagen would vary among species. Almost half of the total protein in jellyfish was found to comprise of collagen. Collagen is an important structural protein which is the most notable characteristic of a repeating Gly-X-Y triplet where X and Y are often proline and hydroxyproline respectively. Therefore, while Hyp content measurement estimates collagen content rapidly, it would be more accurate to determine the amount of collagen by considering the sum of Gly, Pro and Hyp content. Some studies also recommended that lysine and its hydroxylated form, hydroxylysine as components that should be taken into consideration for the approximation of total collagen content (Hausmann & Neuman, 1961; Kimura et al., 1983). The collagen/crude protein values could have been underestimated if glycine, proline and lysine were excluded. In the present study, the amino acids, Gly, Pro and Hyp were found to be constituting of approximately 30–33% of the total amino acids for all the edible jellyfish species studied, regardless of body parts. In addition, this study also explained the relatively high content of lysine in all jellyfish studied, both in the bell and oral arms. In fact, the current study agreed with Kimura et al. (1983) that collagen is the major protein and edible component of jellyfish.

3.6. Elemental analysis

The major elements detected in dry homogenized jellyfish tissues were found to be chlorine (Cl), sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), silicon (Si), zinc (Zn) and phosphorus (P) (Fig. 4). Overall, elemental differences between jellyfish were not very apparent. Only Na and K were significantly different among different species of jellyfish in both tissue parts

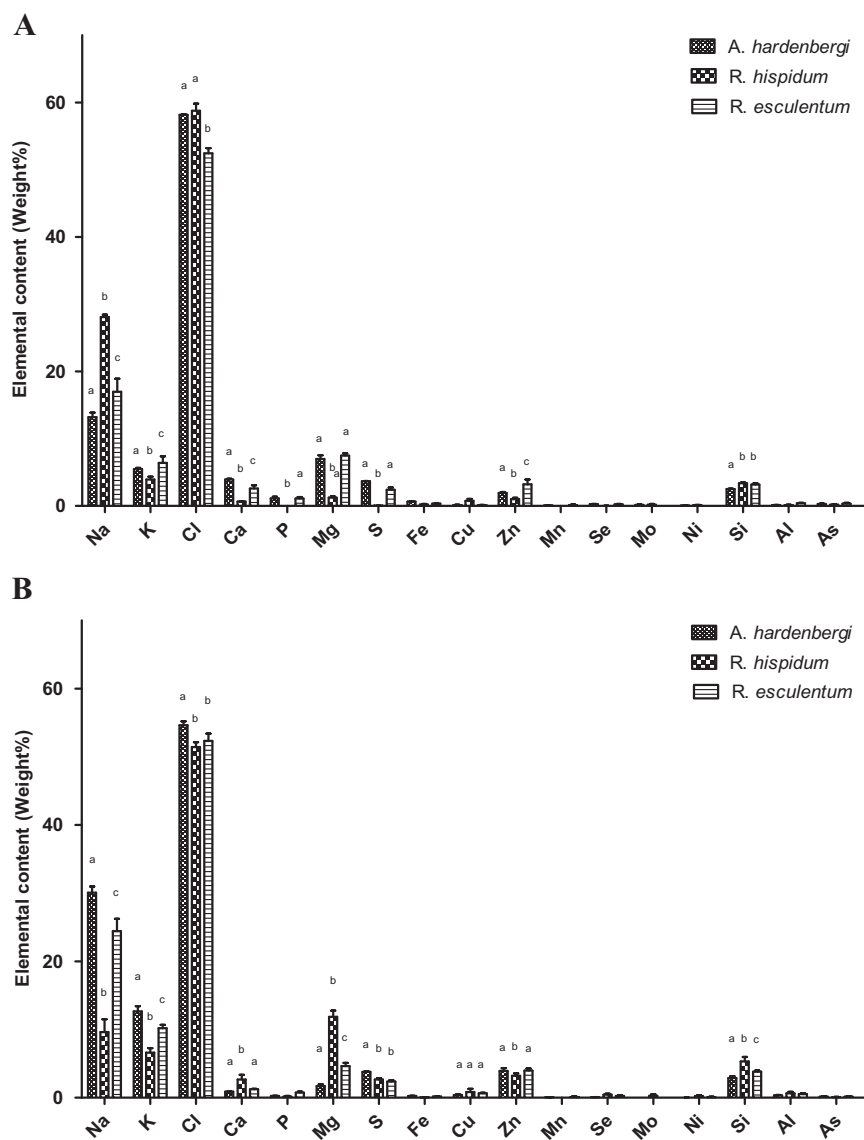


Fig. 4. Elemental EDX microanalysis (Weight%) of different body parts: (A) bell and (B) oral arms of various edible jellyfish. Values ≤ 1 Weight% were considered trace. Data are represented as the mean $\pm$ SD (One-way ANOVA followed by Tukey post hoc test). Groups with different letters (a–c) are significant, $p < 0.05$; $n = 3$.

($p < 0.05$). The high amount of S and P were indicative of high amount of nitrogenous content such as protein and nucleic acids as S and P are rarely found in carbohydrate, lipid and water. Notably, silicon was found to be high in jellyfish of marine origin i.e. *Rhopilema* spp. (red jellyfish and sand jellyfish) while significantly lower ($p < 0.05$) in the river jellyfish which is a brackish water species. This observation suggested that diatoms, which are highly diverse and abundant in the marine ecosystem, to be one of the natural diets of jellyfish, which is in agreement with Pérez-Ruzafa et al. (2002) where scyphozoan jellyfish was reported to exhibit prey preference for large diatoms. Indirect transfer of Si may also be possible through the ingestion of zooplanktons especially tintinnids, fish larvae and copepods which feed on Si-rich phytoplanktons. Other elements found in trace amounts in the jellyfish tissues include, iron (Fe), copper (Cu), manganese (Mn), selenium (Se), molybdenum (Mo), nickel (Ni), aluminum (Al) and arsenic (As), which have been known to be essential in the support of enzymatic reactions, redox protection, bone, teeth and blood health and energy metabolism as nutritional trace minerals. Hazardous elements such as lead (Pb), cadmium (Cd), mercury (Hg) and

inorganic tin (Sn) were not within the detection limit (0.01 Weight %). Elements in jellyfish especially trace elements are highly affected by the habitats of the jellyfish population. Morais et al. (2009) also reported the detection of Al in the jellyfish, *Catostylus tagi* due to Al pollution in the Sado estuary, Portugal where the species was found. The minute arsenic detected was probably contributed by organoarsenicals produced naturally by jellyfish (Hanaoka et al., 2001).

4. Conclusion

Edible jellyfish were found to contain high amount of water, whereas the dry mass was rich in protein, minerals while low in fats and calories. Collagen was found to be the major protein in edible jellyfish and glycine, proline, and glutamic acid were found to be the dominant amino acids. Protein was found to be significantly higher in the oral arms compared to the bells whereas ash content was significantly higher in the bells than the oral arms ($p < 0.05$). Meanwhile, the main elements present within jellyfish

tissues were Cl, Na, K, Mg, S and Si. Data on nutritional values of edible jellyfish, especially those which bear significant commercial importance, is vital information from a food perspective if these organisms are to be directly consumed or used as ingredients in other edible food products. Being high in protein (especially collagen) and mineral content with low calories, edible jellyfish is a potentially feasible source for the development of novel nutraceutical, nutricosmetics and functional foods.

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