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Drying edible jellyfish (*Lobonema smithii*) using a parabolic greenhouse solar dryer

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Abstract

Thailand is one of Southeast Asia's top exporters of salted edible jellyfish. Jellyfish products are generally exported in the form of semi-dried jellyfish. A recent survey on jellyfish distribution in coastal areas in the Gulf of Thailand and the Andaman Sea indicated that most edible jellyfish in the area belong to *Lobonema smithii* and *Rhopilema hispidum*. Drying is an alternative method to preserve food products. In this work, parabolic roof shape greenhouse solar drying of edible jellyfish (*Lobonema smithii*) was studied, and the quality of the dried jellyfish was assessed. The solar dryer system has a 300 kg loading capacity for jellyfish and the resulting dried and rehydrated jellyfish products are described. The moisture content of dried jellyfish decreased to 7.05-11.70% (wb) from 91-92% (wb) after drying for three days and the protein, fat, crude fibre, ash, and carbohydrate content of the dried jellyfish were 68.68%, 0.74%, 0.43%, 9.27%, and 4.67%, respectively. The moisture of the rehydrated jellyfish increased to 37.67-39.07% (wb) after soaking in distilled water for 5 hrs. In terms of colour, the rehydrated jellyfish products were found to be highly similar to salted jellyfish products.

1. Introduction

Fisheries producing edible jellyfish in Southeast Asia have expanded since the 1970s due to increasing demand from markets in China, Japan, and Korea (Kitamura and Omori, 2010). The nutritional composition of commercially edible jellyfish has been widely studied, including collagen (Nagai *et al*., 2000; Song *et al*., 2006; Barzideh *et al*., 2013; Khong *et al*., 2016; Cheng *et al*., 2017; Khong *et al.,* 2017; Ahmed *et al*., 2020) and amino acid (Yu *et al*., 2014). Furthermore, the properties of collagen from jellyfish have been investigated for antioxidant activity (Zhuang *et al*., 2009; Leone *et al*., 2015) immune activity (Sugahara *et al*., 2006; Ming *et al*., 2017), and anti-fatigue activity (Ding *et al*., 2011; Chi *et al*., 2015) have also been studied.

In Thailand, a recent study on jellyfish distribution in coastal areas of 16 provinces in the Gulf of Thailand and six provinces in the Andaman Sea was conducted by the Marine and Coastal Resources Research and Development Institute, Department of Marine and Coastal Resources, Thailand during the period 2010 to 2015. They reported that most edible jellyfishes found in both seas belong to *Lobonema smithii* and *Rhopilema hispidum* (Marine and Coastal Resources and Development Institute, 2015).

After catching jellyfish in the sea, fresh jellyfish are separated into the umbrella and oral arms. Both umbrellas and oral arms are used in processing. For traditional methods of processing, the jellyfish are first processed in salt and alum for about two weeks. Salted jellyfish are then left in brine for 3-4 days and dried on a draining rack at room temperature for 2 days. The jellyfish is then packaged and stored in dried salt. The above jellyfish process using salted products is a traditional method for preserving jellyfish for export to foreign countries. Salted dried jellyfish must be washed to reduce saltiness before food processing. This process is time-consuming and very water intensive.

Drying is a method for preserving foods to extend their shelf life and make them convenient for transportation. In tropical regions in Southeast Asia countries such as Thailand, solar drying is the most

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popular preservation method for rural fruits and vegetables since it is because it is a renewable and environmentally friendly technology (Janjai *et al*., 2011). In the last ten years, many types of solar dryers for agricultural food products have been developed in various countries (Kiburi *et al*., 2010; Belessiotis *et al*., 2011; Janjai, 2012; Reyes *et al*., 2014; Elkhadraoui *et al*., 2015; Čiplienė *et a*l., 2015; Fudholi *et al*., 2015; Nabnean *et al*., 2016; Condorí *et al*., 2017; Eltawil *et al*., 2018; Çiftçioğlu *et al*. 2020; García-Valladares *et al*., 2020).

Chockdee Sea Products Co. Ltd, Samutsongkhram province is one of the biggest export manufacturers of salted jellyfish in Thailand. Salted umbrella jellyfish is its main export product, while salted oral arm jellyfish is not a high-value product. The company, therefore, sought to make more profit from salted oral arm jellyfish by introducing a new jellyfish product. The solar drying of jellyfish presented in this work is an alternative preservation method of jellyfish for domestic market expansion in Thailand. In addition, this dried salted jellyfish could be low weight and convenient to be cooked at home and at restaurants in local markets, while the process also makes it more convenient for export to foreign countries.

Few solar dryers have been developed for high loading capacities of more than 250 kg of fruits or vegetables per batch (Janjai *et al*., 2011; García-Valladares *et al*., 2020; Condorí *et al*., 2017; Sanjai, 2012; Belessiotis *et al*., 2011; Kiburi *et al*., 2010). Moreover, solar dryers, except those described by Condorí *et al*. (2017), used solar radiation with a backup LPG gas burner or biomass stove to dry the food products. The literature review shows that all agricultural food products used with solar drying in the last two decades are fruits and vegetables. To the authors' knowledge, thus far solar drying of eligible jellyfish has not yet been reported in the literature. Therefore, this work is the first report of a solar greenhouse with a parabolic roof shape and polycarbonate sheet construction to dry jellyfish obtained from the seas of Thailand and the quality of the dried jellyfish was evaluated.

2. Materials and methods

2.1 Solar dryer system

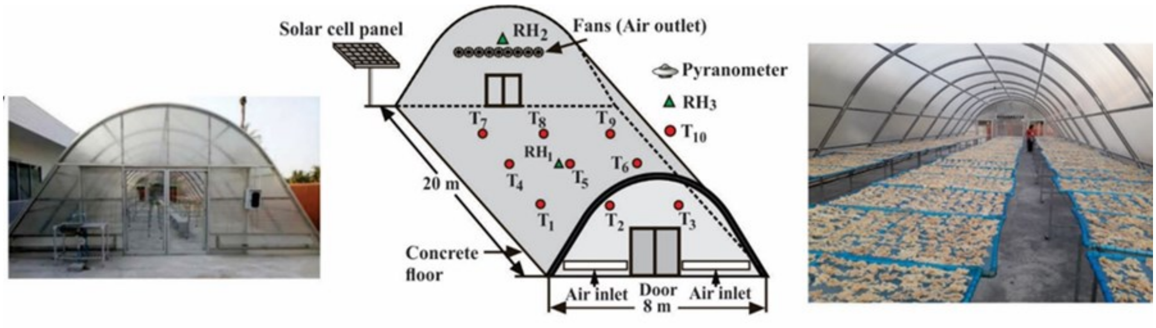
Figure 1(a) shows the solar dryer system used in this study. The dryer system was installed at Chockdee Sea Product Co. Ltd., Samutsongkhram province, Thailand at latitude 13.3736 and longitude 99.9603. Details of the solar dryer system are explained by the schematic shown in Figure 1(b). The system consists of a parabolic roof structure constructed from polycarbonate sheets placed on a concrete floor with an area of 8 × 20 m^2. The front and rear walls of the dryer system are closed by polycarbonate sheets and the door is made of glass located at the middle position of the walls.

Two openings on the front wall are made for an air inlet to allow ambient airflow into the dryers since the temperature inside the dryer is higher than the ambient air. The air and products in the dryer are heated by solar radiation passing through the polycarbonate roof. The hot air then absorbs moisture from the products and is sucked by 9 direct current fans installed on the rear wall of the dryer system to exhaust moisture from within the dryer system. The fans are operated by a 100 W solar cell panel.

Figure 1(c) shows the jellyfish trays placed on shelves in three longitudinal rows. The left, middle and right rows of the trays contained variously sized jellyfish, including S (small), M (medium), and L (large), respectively. Each row consisted of eighteen trays with each try being 1 m wide × 2.2 m long. Furthermore, all 54 trays could be used to dry about 300 kg of jellyfish.

The shelves of the horizontal front row were placed at a position of 1 m from the front wall. The shelves of the last row were placed at a position of 1 m from the rear wall. Therefore, the active length of the jellyfish trays on the shelves for drying was 18 m. The drying area is 18 m long and divided into 3 zones: front, middle, and back zones, with each zone being 6 m long.

Three jellyfish samples sized S, M, and L were



(a) (b) (c)

Figure 1. (a) Solar dryer system, (b) schematic of solar dryer system and (c) jellyfish under solar drying.

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placed in the middle of each zone at positions 4, 7, and 16 m from the front wall. The samples were monitored to observe the uniformity of the moisture content.

A total of nine thermocouples were installed along the shelves of the jellyfish trays at different positions in the three zones, as shown in Figure 1(b). The relative humidity of the air at the centre and at the outlet inside the dryer system was measured using two hygrometers (Electronic, model EE23B). A pyranometer (Kipp and Zonen, model CMP11) was installed near the dryer system to measure the solar radiation incident on the roof of the dryer system. Furthermore, the temperature and relative humidity of the ambient air outside the dryer system was also measured, as seen in Figure 1(b).

2.2 Sample preparation

A total of 300 kg of oral salted jellyfish arms were used for the drying. The samples were washed with water to remove salt and classified into three sizes, small (S) <40 g, medium (M) 41-69 g, and size (L) > 70 g. In the left, middle, and right rows inside the dryer system, trays were placed and spread with jellyfish samples of all sizes (S, M, and L), as shown in Figure 1(c).

2.3 Experimental procedure

The drying experiments were conducted between 27 December 2019 and 29 December 2019. Solar radiation, relative humidity, and temperature were recorded every 10 minutes using a 40-channel data logger (Yokogawa, model DC 100) from 7.00 am to 5.00 pm.

2.4 Measurement of dried product quality

2.4.1 Colour measurement

The colour of the dried or dehydrated products was measured using a colourimeter (Minolta, model CR-300) in CIE chromaticity coordinates L*, a*, and b*, where L* describes lightness, a* describes intensity in the red-green axis, and b* describes intensity in the yellow-blue axis. The colour of the rehydrated products was also measured to compare the colour change after the rehydration process.

2.4.2 Chemical analysis

The chemical composition of the sample was as follows. Protein, fat, crude fibre, and ash were determined according to the method established by AOAC (2000). Protein content was determined using the Kjeldahl method with N×6.25. The Soxhlet extraction method was used to determine fat content. The crude fibre was analysed by the loss of ignition of the dried residue remaining after digestion of the sample and determined by weight difference. Ash content analysis was conducted in a muffle furnace at 550°C for 3 hrs until white or light grey ash was obtained. Carbohydrate content was calculated by subtracting the protein, fat, fibre, and ash content from the sample. Chemical composition results are reported as g/100 g dry matter.

2.4.3 Determination of moisture content

Moisture content measurements started on 27 December 2019 between 7.30 am to 3.30 pm and were conducted using the oven drying method according to AOAC (2000). About 3 g of the sample was taken and dried in the oven (Hot air oven [BINDER, FD, Germany]) at 105°C for 3 hrs, then cooled in a desiccator until a constant weight was achieved and weighed periodically at 2 hrs intervals using an electronic digital balance (Tanita, KD-200, Thailand). Finally, the moisture content of the product was determined. Drying continued on subsequent days until a constant moisture content of about 10% (wb) was achieved and the moisture content corresponded to that of high-quality dried products. In the experiment, jellyfish samples sized S, M, and L were placed in the front, middle, and back zones (Section 2.2) and were used for moisture content measurements.

2.4.4 Determination of dehydration ratio

The typical jellyfish 5 g samples sized S, M, and L in the front, middle and back zones, were measured before the solar drying started on 27 December 2019. Drying continued until constant moisture content was achieved. The dried jellyfish samples were then measured again. The dehydration ratio of solar-dried jellyfish was calculated by the following formula:

$$\text{Dehydration ratio} = \frac{\text{Mass of sample before drying}}{\text{Mass of dried sample}}$$

Therefore, a higher dehydration ratio indicates a higher rate of solar drying.

2.4.5 Determination of rehydration ratio

Rehydration involves refreshing a dehydrated or dried product in water. The dried jellyfish samples were rehydrated according to the method by Doymaz and İsmail (2011). Rehydration tests were performed at 25°C in distilled water for 5 hrs. About 5 g of dried products were immersed in glass beakers containing water at a ratio of 1:50 (w/w). At 30-minute intervals, the samples were taken out, carefully blotted with tissue paper to eliminate water on the surface, and then weighed on an electronic digital balance (Tanita, KD-200, Thailand). The samples were then immediately returned to the same soaking water. Dried jellyfish samples were rehydrated over a period of 5 hrs until a constant weight of rehydrated samples was achieved. The rehydration ratio was determined by the following formula (Doymaz and

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İsmail, 2011):

$$\text{Rehydration ratio} = \frac{\text{Mass of rehydrated sample}}{\text{Mass of dehydrated sample}}$$

Therefore, the rehydration ratio is the capability of water absorption of dried products. A higher rehydration ratio indicates a higher rate of water absorption.

2.4.6 Statistical analysis

For all measurements described in items 2.4.1 to 2.4.4, three replicates were performed for each sample. The experimental results were expressed as mean ± standard deviation (SD). Statistical analysis was performed using SPSS software (SPSS Statistics 19.0). A one-way analysis of variance (ANOVA) was conducted to analyse the data and Duncan's test was used to separate the mean values at the 0.05 significance level.

3. Results and discussion

3.1 Experimental results

Figure 2(a) shows the variations of solar radiation during the drying experiment of the jellyfish samples. Solar radiation increased sharply from 8.00 am to noon and then considerably decreased in the afternoon. However, in the first two days, there was a random fluctuation due to clouds on 27 December 2019 (Figure 2a) and rain on 28 December 2020 (Figure 2b), while there was a clear sky on the final day of drying. The daily solar radiation energy during the experiment was 16.875 on the 27th of December 2019, 15.178 on the 28th, and 19.340 MJ/m^2 on the 29th.

Figure 3 shows the variations of relative humidity inside the solar dryer (RH1), at the outlet (RH2), and at the ambient air relative humidity (RH3). The low relative humidity is more favourable for drying due to the increased evaporation capacity of the air. It should be noted that on the first day (Figure 3a), between 8.00 am and 2.00 pm the relative humidity of the ambient air was lower than the relative humidity at the outlet of the solar dryer. This phenomenon was unusual for the general drying process. This could be due to the very high initial moisture content of about 92% (wb) of the jellyfish samples. After noon, the temperature inside the dryer increased and the moisture content of the jellyfish samples then evaporated and was exhausted out of the dryer by the fans. This resulted in the high relative air humidity at the outlet. After the first day of drying

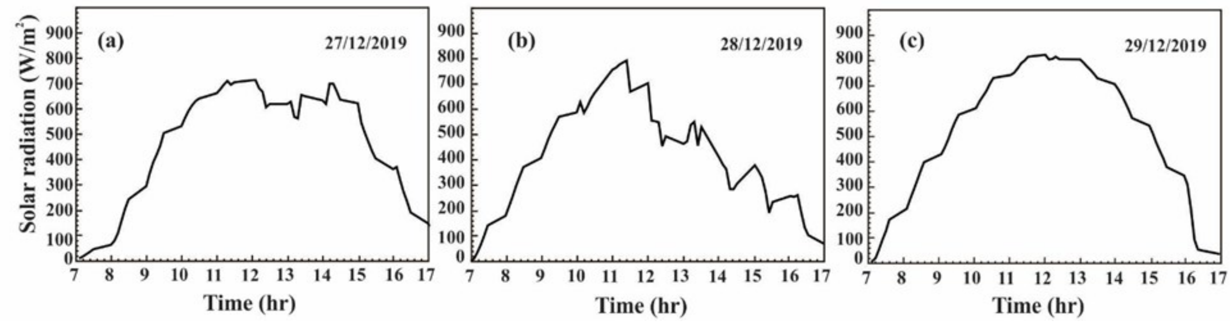

Figure 2. Variations of solar radiation during the drying experiment.

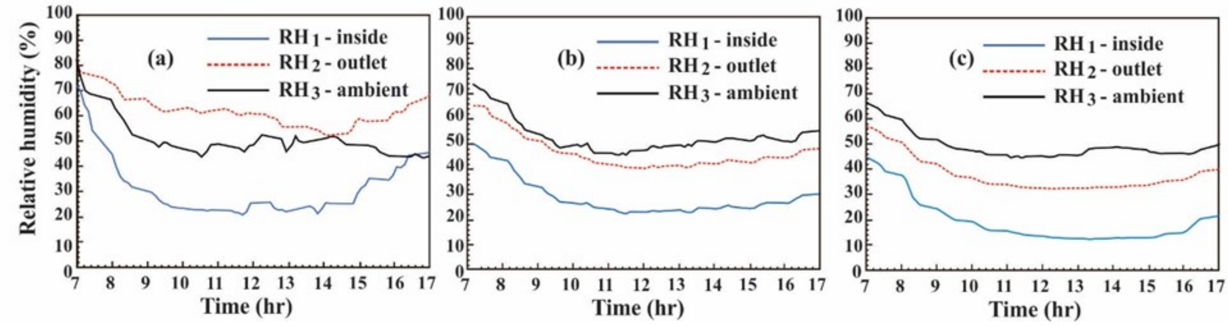

Figure 3. Variations of relative humidity inside the solar dryer (RH_1), at the outlet (RH_2) and those of the ambient air (RH_3) with time of the day.

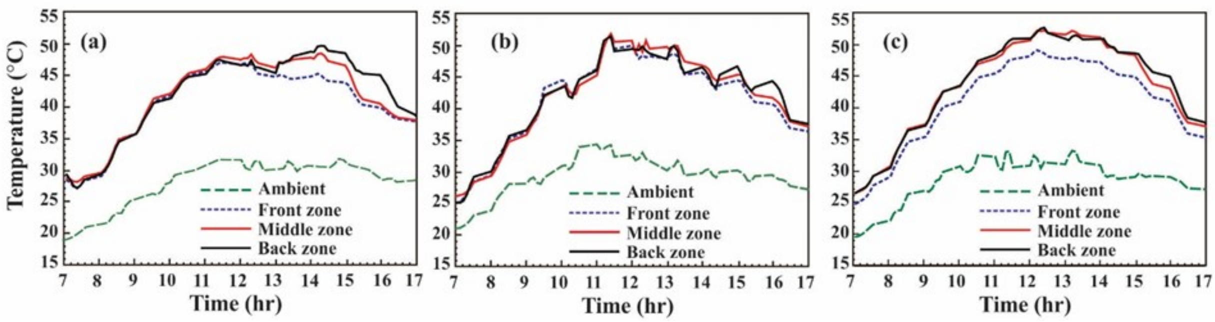

Figure 4. Variations of temperature at three zones and ambient air temperature with time of the day.

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(Figure 3a), some water in the jellyfish samples was already exhausted out of the dryer through the fans. Therefore, on the second day (Figure 3b) and third day (Figure 3c) of drying, the relative humidity of the ambient air was higher than the air inside and at the dryer outlet. Furthermore, the relative humidity slowly decreased from 7.00 am to noon due to the air temperature inside the dryer increasing from 25°C to about 52°C, as shown in Figures 4b and 4c.

Figure 5 shows the variations of moisture content of all jellyfish sizes at different zones from 27 to 29 December 2019. On the first day of drying, the initial moisture content of all jellyfish sizes in all zones was about 92% (wb). It is seen that the drying rates of all three sizes in the three zones of the greenhouse dryer slowly decreased on the first day of drying. At the midday of the second day, the moisture content fell steeply, especially in the M and L-sized samples. Three days were required to completely dry three hundred kilograms of all jellyfish sizes in the greenhouse solar dryer and the moisture content of all dried jellyfish sizes in all zones decreased to 7.05-11.70 % (wb). The constant drying rate was observed on the third day of drying. These observations were similar to other reports (Elkhadraoui *et al.,* 2015; Fadhel *et al*., 2005; Usub *et al*., 2008) that drying occurred during the falling rate period in which there was a steep fall in moisture content during initial drying stages before slowing in later stages. Moreover, the very high initial moisture content of the jellyfish and the high relative humidity of the dryer could explain why the drying rate of jellyfish on the first day of drying was very low compared to the second day. A similar trend was observed while drying bananas which have an initial moisture content of 70% (wb) (Janjai *et al*., 2011). Additionally, it is seen that the moisture content of the L-sized samples more rapidly decreased in all three zones compared to the M and S-sized samples. The moisture content of jellyfish in the middle and back zones rapidly decreased compared to the front zone. These results are consistent with the temperature of the greenhouse dryer (Figure 4).

3.2 Qualities of the dehydrated product

The jellyfish samples were analysed for protein content (Kjeldahl method), fat content (Soxhlet method), crude fibre content, ash content, and carbohydrate content according to the AOAC (2000) method. The protein, fat, crude fibre, ash, and carbohydrate content results of the dehydrated jellyfish samples are shown in

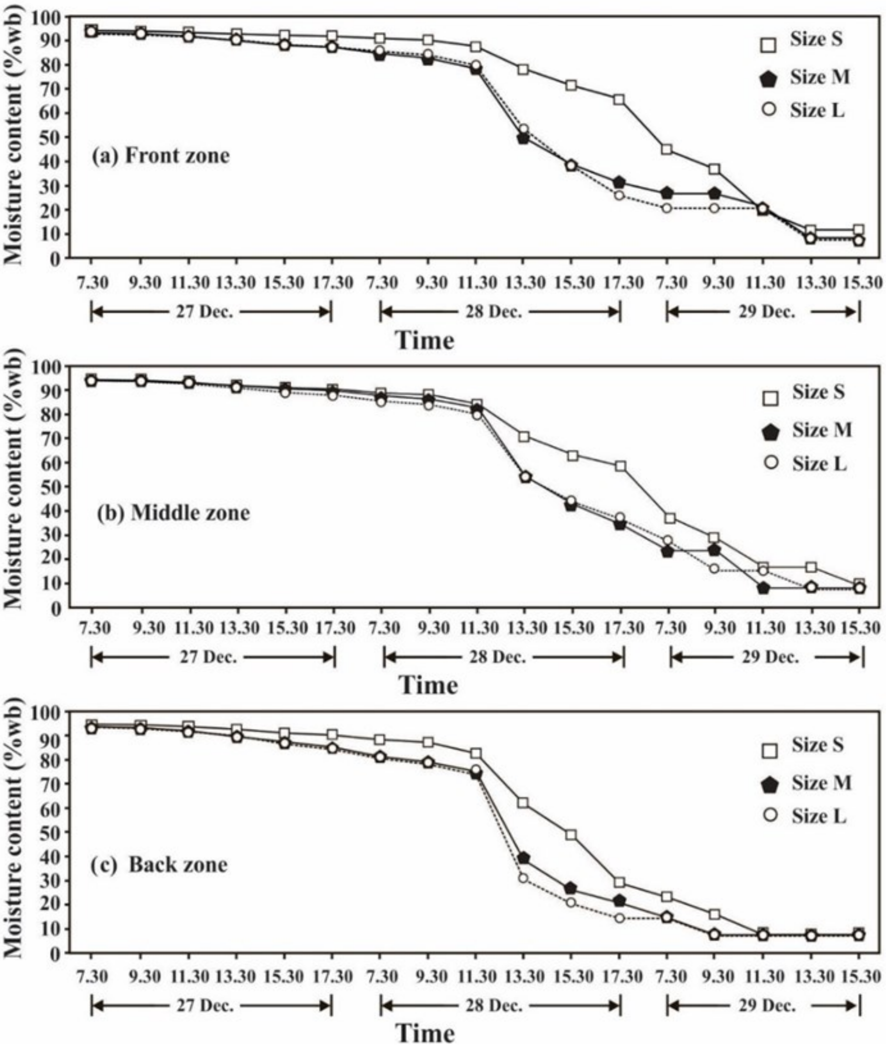

Figure 5. Comparison of moisture contents in three jellyfish sizes at: (a) front zone, (b) middle zone and (c) back zone.

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Table 1.

The protein, fat, crude fibre, ash, and carbohydrate content of the dehydrated jellyfish sample were 68.68%, 0.74%, 0.43%, 9.27%, and 4.67%, respectively. Edible jellyfish were found to be rich in protein and ash content, had low calorific values, and negligible fat content. In this study, it was found that the protein content was higher than the ash content. This result is consistent with Khong *et al.* (2016) that the oral arms of edible jellyfish have total protein content higher than ash content, while the bell of edible jellyfish had total ash content higher than protein content.

Table 1. Chemical compositions of dried jellyfish

Chemical compositions	Content (%)
Protein	68.68±0.63
Fat	0.74±0.02
Crude fibre	0.43±0.45
Ash	9.27±0.26
Carbohydrate	4.67±0.75

3.3 Qualities of rehydrated products

3.3.1 Colour change

The colour of dried and rehydrated products is one of the important criteria for consumer acceptability and the market value of products (Wang *et al*., 2014). Figure 6 shows photographs of typical dried and rehydrated jellyfish products sized S, M, and L obtained from the middle zone of the dryer. Similar photographs were also obtained from the front and back zones but are not shown here due to their close similarity.

The colour of the dried and rehydrated jellyfish products was measured in CIE chromaticity coordinates L*, a*, and b*. Typical colour measurement results of salted, dried, and rehydrated products sized S, M, and L in the front, middle and back zones of the dryer system are shown in Table 2.

It is seen that the L* values of all sizes of the dried or dehydrated jellyfish products from the middle and back zones of the greenhouse dryer ranged from 44.73±0.57 to 51.63±1.14, compared to 47.33±0.41 to 55.63±0.06 for the L* values. This indicates that the dried jellyfish products are darker than the of rehydrated jellyfish products.

From Figure 6(b), it is clearly observed that there was no significant difference in the colour of dried jellyfish products of all sizes and whether from the front, middle, or back zones. In addition, Figure 6(c) also shows no significant difference in the colour of rehydrated jellyfish products of all three sizes in all three zones. Furthermore, it can be observed that the colour of rehydrated jellyfish products is almost the same as those of initial salted-jellyfish products (Figures 6a and 6c).

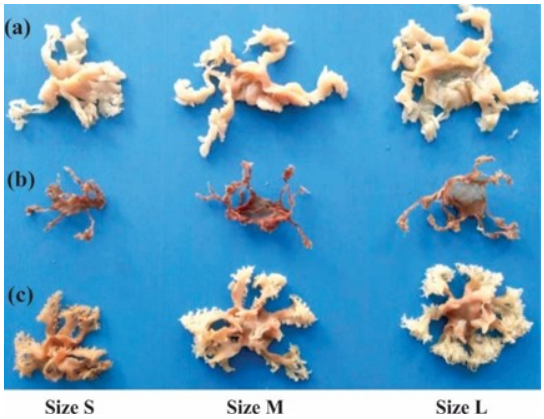

Figure 6. Photographs of (a) salted, (b) dried and (c) rehydrated jellyfish

3.3.2 Rehydration characteristics

Rehydration property is one of the most important indicators of quality criterion for dried foods (Deng *et al*., 2014; Akonor *et al.,* 2016). The results of the measurements of dehydration ratio, rehydration ratio, and moisture content in dried and rehydrated jellyfish products of sizes S, M, and L in the front, middle and back zones of the greenhouse dryer are given in Table 3.

For the dehydration property, it is clearly observed that in all three zones, the lowest and highest dehydration

Table 2. Comparison of colour in three jellyfish sizes at the front zone, middle zone, and back zone

Zone	Size	Dehydrated products			Rehydrated products		
		L*	a*	b*	L*	a*	b*
Front	S	44.73±0.57^{b}	9.83±0.54^{a}	16.70±0.51^{a}	47.33±0.41^{b}	8.60±0.10^{c}	21.83±0.83^{c}
	M	50.11±0.46^{a}	9.58±0.15^{a}	16.13±0.91^{a}	50.67±0.32^{a}	11.33±0.58^{b}	25.67±0.45^{b}
	L	50.53±0.45^{a}	8.61±0.41^{b}	15.23±0.45^{b}	50.90±0.10^{a}	13.17±0.40^{a}	29.60±0.40^{a}
Middle	S	45.63±0.48^{b}	10.10±0.35^{a}	16.95±0.96^{a}	50.76±0.75^{b}	10.13±0.31^{b}	26.27±0.57^{c}
	M	50.90±0.60^{a}	9.40±0.51^{b}	16.76±0.72^{a}	51.23±0.60^{ab}	10.37±0.46^{ab}	26.93±0.55^{b}
	L	51.08±0.57^{a}	8.66±0.64^{c}	14.53±1.01^{b}	52.43±0.40^{a}	11.23±0.58^{a}	28.70±0.26^{a}
Back	S	46.36±0.92^{c}	9.21±0.56^{a}	16.60±0.79^{ns}	48.70±1.05^{c}	11.20±0.26^{c}	23.97±0.95^{c}
	M	50.23±0.83^{b}	8.80±0.63^{ab}	15.85±0.95^{ns}	52.10±1.30^{b}	13.00±0.10^{a}	26.70±1.13^{b}
	L	51.63±1.14^{a}	8.48±0.27^{b}	15.58±0.96^{ns}	55.63±0.06^{a}	11.87±0.15^{b}	32.77±0.15^{a}

Values are presented as mean±standard deviation. Values with different superscript within the same column for different zone are significantly different ($p \leq 0.05$). ^{ns}no significant different ($p \geq 0.05$)

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Table 3. Comparison of dehydration and rehydration in three jellyfish sizes at the front zone, middle zone, and back zone

Zone	Size	Dehydration property		Rehydration property	
		Dehydration ratio	Moisture content (%)	Rehydration ratio	Moisture content (%)^{ns}
Front	S	12.05±0.50^{b}	11.70±0.59^{a}	3.69±0.09^{a}	37.88±0.80
	M	16.33±0.32^{a}	8.38±0.62^{b}	3.41±0.16^{a}	38.34±0.38
	L	16.79±1.25^{a}	7.50±0.16^{c}	2.74±0.20^{b}	39.07±0.61
Middle	S	11.89±0.24^{b}	9.48±0.06^{a}	3.48±0.12^{a}	37.67±0.51
	M	16.34±0.39^{a}	8.50±0.17^{b}	3.44±0.21^{a}	37.82±0.28
	L	16.73±1.47^{a}	7.90±0.80^{c}	2.55±0.13^{b}	38.43±0.57
Back	S	11.91±1.23^{b}	7.53±0.16^{a}	3.35±0.20^{a}	38.21±0.69
	M	16.19±0.68^{a}	7.44±0.72^{a}	3.17±0.11^{a}	38.43±0.21
	L	16.60^{a}±1.95^{a}	7.05±0.34^{b}	2.64±0.26^{b}	39.02±0.61

Values are presented as mean±standard deviation. Values with different superscript within the same column for different zone are significantly different ($p \leq 0.05$). ^{ns}no significant different ($p \geq 0.05$).

ratios were obtained in the S and L size dried jellyfish samples, respectively. The highest and lowest moisture contents were obtained in S and L size dried jellyfish samples, respectively. This confirms that the highest dehydration ratio (size L) had the highest rate of solar drying which resulted in the lowest moisture content of the dried jellyfish samples.

In terms of desired rehydrated properties, a high rehydration ratio and high moisture content in the rehydrated sample are preferred. For the rehydration property in this study, it is clearly observed that in all three zones, the highest and lowest rehydration ratios were obtained in rehydrated jellyfish samples sized S and L, respectively. The lowest and highest moisture contents were obtained in rehydrated jellyfish sized S and L, respectively. The highest rehydration ratio of size S indicates the highest rate of water absorption. Although the highest rehydration ratio for size S means that this size had the highest rate of water absorption, the moisture content was found to be lowest compared to sizes M and L. This is due to the jellyfish size S containing much less water than the M and L sizes.

4. Conclusion

A greenhouse solar dryer system for drying oral arms of jellyfish with a loading capacity of 300 kg was presented in this work. Three sizes of jellyfish, small (S) < 40 g, medium (M) 41-69 g, and large (L) > 70 g were used for drying. In the left, middle, and right rows inside the dryer system, trays were placed which were spread with jellyfish samples of all sizes. Drying experiments were carried out between 27 and 29 December 2019. Solar radiation, relative humidity, and temperature were recorded every 10 minutes from 7.00 am to 5.00 pm. Colour, moisture content, dehydration ratio, and rehydration ratio were determined. The drying results show that the moisture content in all three jellyfish sizes placed in different zones inside the solar dryer system decreased to 7.05-11.70% after drying for three days. These moisture content values are acceptable for high-quality dead products. Therefore, it can be concluded that the solar drying system is suitable for the presented purpose.

Conflict of interest

The authors declare no conflict of interest.

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