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EFFECT OF DIFFERENT DRYING METHODS ON TOTAL LIPID AND FATTY ACID PROFILES OF DRIED *Artemia franciscana* BIOMASS

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ABSTRACT

Frozen Artemia (Artemia franciscana) biomass was dehydrated by outdoor sun drying and three indoor drying techniques which consisted of convective hot air drying (HA), intermittent microwave combined with convective hot air drying (MWHA) and oven drying at temperatures of 50, 60 and 70°C. The aim of this study was to evaluate the effect of different drying techniques at different temperatures on the contents of total lipid and fatty acid profile of Artemia biomass. The results showed that among three indoor drying techniques, the shortest drying time was 57-74 min for MWHA, followed by 380-480 min (HA) and 480-1320 min (oven drying), while sun drying showed the longest dehydration duration of 1380 min compared to other drying methods. In addition, drying time was relatively decreased with increasing temperature. For the three indoor drying methods, the contents of total lipid and fatty acids of dried Artemia biomass were not significantly different (P>0.05) from the control in most cases. On the contrary, sun drying resulted in a high loss of these substances compared to the control. Moreover, at the same drying temperature, the longer drying time caused a higher loss of nutrients in the dried products as shown by the values in the MWHA sample which was slightly higher than in other two drying methods. Nonetheless, significant differences between the three indoor drying methods were not observed (P>0.05). In general, the intermittent MWHA drying is a promising technique, which could produce high quality dried products in short drying times. However, it might not be suitable for large-scale application because of high capital investment and operating costs. Therefore, sun drying method should be improved to optimize the use of renewable energy sources through application of solar dryer.

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1 INTRODUCTION

Lipids and fatty acids play an important role in the nutrition of crustaceans and fish. They mainly function as a source of energy and for the maintenance of the functional integrity of biomembranes (Tocher, 2003). Furthermore, the essential fatty acid content of artificial diets has been found to have a strong impact on survival, growth, reproduction and stress tolerance of shrimp and fish species (Wouters *et al*., 2002; Takeuchi and Murakami, 2007). Fresh *Artemia* biomass has been considered a good source of proteins, lipids and highly unsaturated fatty acids. However, *Artemia* biomass contains a high water content (approximately 90% water) and is rich in proteolytic enzymes; the soft *Artemia* body is thus subject to decomposition after being collected few hours. Therefore, appropriate preservation methods are needed to keep a good quality of biomass (Sorgeloos *et al*., 2001).

Previous studies have confirmed that drying is an appropriate method of product preservation. If the quality of dried *Artemia* biomass can be maintained, it may have certain advantages over fresh or frozen products due to the low cost of transportation, reduced space needed for storage and longer shelf-life (Chua and Chou 2005; Kamalakar *et al*., 2013; Anh *et al*., 2014). Previous studies have demonstrated that dried *Artemia* biomass can be used as an ingredient in postlarval shrimp and prawn feeds (Naegel and Rodriguez-Astudillo, 2004; Anh *et al*., 2009). Moreover, freeze-dried meal of adult *Artemia* has also been used as a partial or sole ingredient of shrimp broodstock diets increasing diet ingestion and stimulating ovarian maturation in commercial scale trials (Wouters *et al*., 2002). Several technologies have been described for drying plant and animal products, such as freeze drying, vacuum drying, microwave drying, hot air drying, conventional sun drying etc., or combinations of some of these methods (George *et al*., 2004; Hu *et al*., 2013). A choice of drying technique depends upon the desired quality and flavour of the dried products, the initial moisture content and the chemical composition of products (Chua and Chou 2005; Kamalakar, *et al*., 2013). Drying time and temperature can be considered the most important operating parameters affecting dried product quality, which is usually evaluated on the basis of nutrient retention and sensory characteristics (Chukwu 2009; Duan *et al*., 2010). Hence, different drying methods would have a direct impact on nutrient availability. Lipid and fatty acid profiles of *Artemia* as feed are important for the survival, growth and reproduction of shrimp and fish species (Sorgeloos *et al*., 2001; Wouters *et al*., 2002). However, the drying process may cause the loss of these substances through oxidative deterioration. Therefore, the main objective of this study was to compare the contents of total lipid and fatty acids of *Artemia* biomass, dried using different drying methods and at different temperatures, aiming to assess the effect of the drying method on the dietary lipids in aquafeeds.

2 MATERIALS AND METHODS

2.1 Drying experiments

The drying techniques and drying equipments were provided by the Department of Mechanical Engineering, College of Engineering Technology, Can Tho University. Four drying methods were tested: outdoor sun drying and three indoor drying methods including convective hot air (HA) drying, combination of intermittent microwave and convective hot air drying (MWHA), and oven drying.

For the convective hot air drying and combined microwave-convective hot air drying, the drying system was specially designed, and consisted of a hot air-microwave oven, equipped with an adjustable temperature and velocity convective mode, and an adjustable power continuous or intermittent output microwave mode (trial set). In this experiment, the equipment was operated using the intermittent mode. For all convective drying treatments, the air velocity was set at 1.5 m s^{-1}. The settings of the respective drying techniques were as follows:

- Convective hot air drying: convective air temperatures were set at 50, 60 and 70°C.
- Intermittent microwave combined with convective hot air drying: convective air temperatures were set at 50, 60 and 70°C, microwave power was set at the medium high level and the intermittent time was 2 min with a cycle time of 1 min ‘on’ and 2 min ‘off’ to prevent the samples from becoming charred or burnt.
- Electric oven drying: temperatures were set at 50, 60 and 70°C.
- Outdoor sun drying: *Artemia* samples were exposed directly to sunlight (the plastic nets containing *Artemia* biomass were placed on the cement floor from 8:00 to 17:00 h. At night, these samples were kept in airtight nylon bag; sun drying was continued in the next day until the desired moisture content was obtained.

Each drying trial was repeated three times and the final moisture content for all drying techniques was ≤13%. See Table 1 for abbreviations of drying techniques.

Weight loss was determined at intervals of 5 - 15 min for MWHA and 2-4 hours for HA and oven drying. The *Artemia* samples were taken out, quickly weighed on an electronic balance with 0.1 g accuracy and returned to the drier.

2.2 Sample preparation

Fresh *Artemia* biomass was obtained from the experimental ponds in Bac Lieu province. The freshly-harvested biomass was transported in a plastic box with ice to the Laboratory of Can Tho University and stored at -15°C until use. All *Artemia* biomass utilized in this experiment was from the same batch. Prior to each drying experiment, *Artemia* biomass was taken out of storage, thawed and washed with tap water to eliminate impurities. Excess water in *Artemia* samples was removed with tissue paper and *Artemia* samples of 100 g were spread on a plastic net in a layer with a thickness of about 4 mm. For sun drying, 0.3% of antioxidant (butylated hydroxytoluene, BHT) was added to the sample before drying.

2.3 Sample analysis

Moisture content, total lipid and fatty acid contents of the *Artemia* samples were determined before and after drying.

Dried *Artemia* samples were ground into fine particles and stored at -80°C until further analysis, and frozen *Artemia* biomass was used as control. Moisture was determined by drying in an oven at 110°C until (between 3-4 h) constant weight. Total lipids were extracted according to the method described by Ways and Hanahan (1964). Fatty acid composition was analytically verified by flame ionization detection (FID) after injecting the sample into a Chrompack CP9001 gas chromatograph, according to the procedure described by Coutteau and Sorgeloos (1995). Integration and calculations were done with the software program Maestro (Chrompack) at Laboratory of Aquaculture, *Artemia* Reference Center, Ghent University, Belgium.

2.4 Statistical analysis

The contents of total lipid and fatty acid composition of *Artemia* samples subjected to different drying methods and temperatures were compared with the frozen *Artemia* by one-way ANOVA. The Tukey HSD post-hoc analysis was used to detect differences between means. Significant difference was considered at $P<0.05$ (SPSS for Windows, Version 14.0). All percentage values were normalized through a square root arcsine transformation prior to statistical treatment.

3 RESULTS

3.1 Drying time

The moisture content and drying time of *Artemia* biomass at temperatures of 50, 60 and 70°C by different drying methods are shown in Table 1. All drying treatments resulted in similar moisture content. Regardless of other drying parameters, drying temperatures at 50, 60 and 70°C, employing the intermittent microwave combined with convective hot air drying (MWHA significantly shortened drying time (57-74 min) compared with HA alone (380-460 min), oven drying (480-1320 min) and open sun drying (1380 min). Moreover, for the same drying temperature, drying time in HA drying was faster than in oven drying. Increased temperature resulted in a shorter drying time. Generally, drying time was fastest in the MWHA drying which was 10, 14 and 21 times faster than HA, oven and sun drying, respectively.

Table 1: Drying time at different drying techniques

Drying technique	Initial moisture content (%)	Final moisture content (%)	Drying time (min)
Drying at 50°C			
Convective hot air (HA50)	86.7±0.5	12.2±1.2	960±30
Microwave+HA (MWHA50)	88.4±0.7	12.6±0.8	74±4
Oven (Oven50)	87.6±0.7	12.3±1.4	1320±30
Drying at 60°C			
Convective hot air (HA60)	86.7±1.0	12.6±1.1	560±10
Microwave+HA (MWHA60)	87.5± 0.8	12.4±0.6	66±7
Oven (oven60)	86.7±0.6	12.6±0.9	870±20
Drying at 70°C			
Convective hot air (HA70)	87.5±0.6	12.4±0.7	380±10
Microwave+HA (MWHA70)	88.1±0.9	12.2±0.5	57±3
Oven (Oven70)	86.9±1.0	12.5±0.6	480±30
Open sun drying	87.8±0.3	12.3±0.6	1380±550

3.2 Total lipid of dried *Artemia*

Total lipids of dried *Artemia* biomass are shown in Figure 1. For the three indoor drying methods (HA, MWHA and oven drying), total lipids of dried *Artemia* were similar for the different drying temperatures of 50, 60 and 70°C (range 10.29-10.93%). Statistical analysis indicated that the HA70, Oven50 and Oven70 samples showed statistically lower values than the frozen sample (11.35%). In addition, total lipid content of sun-dried biomass (9.82%) was significantly lower than the control and HA50, HA60, MWHA and Oven60 samples ($P<0.05$).

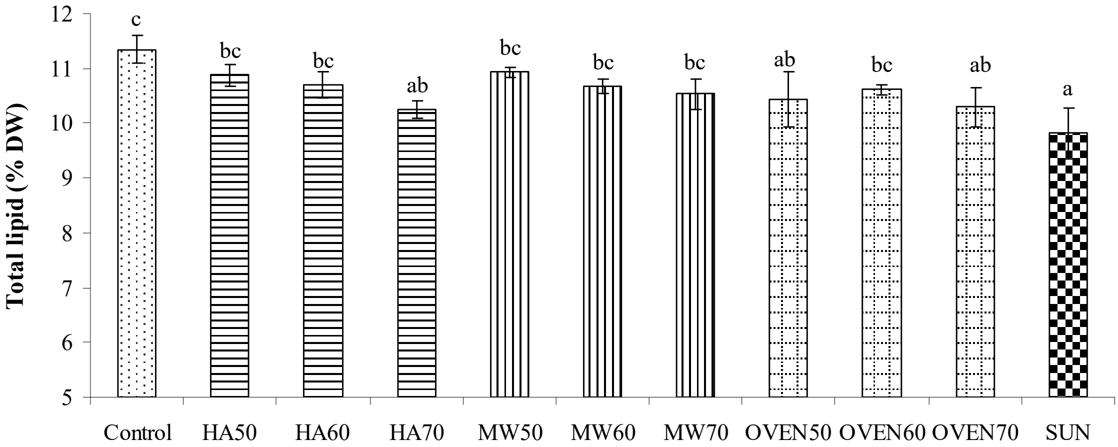

Fig. 1: Total lipids (% of DW) of frozen (control) and *Artemia* biomass (mean ±STD) dried using different drying techniques and temperatures

Different letters on top of the bars indicate significant differences (p<0.05) among treatments

3.3 Fatty acid composition of dried *Artemia*

Data on fatty acid composition of dried *Artemia* biomass are presented in Table 2. There was no significant effect of three indoor drying methods on the contents of eicosapentaenoic acid (EPA, 20:5n-3), docosahexaenoic acid (DHA, 22:6n-3) and arachidonic acid (ARA, 20:4n-6), except for DHA values in Oven60 and Oven70 samples, which were significantly lower than in the control. In sun-dried biomass, the EPA content was significantly reduced as compared with the control, HA50 and MWHA50. Additionally, no significant difference in DHA was observed between the sun-dried sample and the Oven60 and Oven70 samples ($P>0.05$) but the DHA value of the sun-dried sample significantly differed from the other drying treatments ($P<0.05$) and the control. Although the values of ARA and total saturated fatty acids (SFA) in sun-dried samples were lower than the control and other drying methods, statistical differences were not detected.

For the three indoor drying methods, total mono-unsaturated fatty acid (MUFA) levels were similar in all drying temperatures, with levels for HA70, Oven50 and Oven70 being significantly lower than in frozen biomass. The sun-dried sample showed a significant reduction in total MUFA content compared to the control and other drying methods ($P<0.05$). Furthermore, total polyunsaturated fatty acid (PUFA) levels and total n-3 PUFA tended to decrease slightly with increasing temperatures, with the HA70 and Oven70 samples similar to the sun-dried product and significantly lower than the control. Total n-6 PUFA contents showed the same trend as total n-3 PUFA in the three indoor drying methods. However, significant differences were only found between the sun-dried sample and the control ($P<0.05$). The ratios of n3/n-6 were nearly equal in all samples, ranging from 1.8 to 2.2. In general, there were no significant differences in total lipid and fatty acid levels of dried *Artemia* between the drying temperatures of 50, 60 and 70°C although slightly lower values were observed at higher drying temperatures. Contents of total lipids and fatty acids of the indoor-dried *Artemia* samples differed less from the control than that of the sun-dried sample.

Table 2: Fatty acid composition (mg g^{-1} DW) of *Artemia* biomass dried using different drying techniques

Drying techniques		Convective hot air drying			Microwave + HA drying			Oven drying			Sun drying
Fatty acids	**Control***	**50°C**	**60°C**	**70°C**	**50°C**	**60°C**	**70°C**	**50°C**	**60°C**	**70°C**	
20:5n-3	11.81 ±0.55^{b}	11.27 ±0.22^{b}	10.62 ±0.24^{ab}	10.62 ±0.29^{ab}	11.44 ±0.37^{b}	10.88 ±0.33^{ab}	10.69 ±0.86^{ab}	10.84 ±0.65^{ab}	10.63 ±0.48^{ab}	10.53 ±0.87^{ab}	9.30 ±1.24^{a}
22:6n-3	0.51 ±0.04^{c}	0.42 ±0.02^{bc}	0.36 ±0.08^{ab}	0.31 ±0.05^{ab}	0.40 ±0.03^{bc}	0.39 ±0.03^{bc}	0.43 ±0.06^{bc}	0.39 ±0.04^{bc}	0.36 ±0.04^{ab}	0.29 ±0.02^{ab}	0.19 ±0.11^{a}
20:4n-6	3.59 ±0.11^{a}	3.31 ±0.39^{a}	3.37 ±0.22^{a}	3.15 ±0.16^{a}	3.41 ±0.39^{a}	3.26 ±0.35^{a}	3.30 ±0.20^{a}	3.32 ±0.39^{a}	3.23 ±0.28^{a}	3.22 ±0.14^{a}	2.59 ±0.42^{a}
ΣSFA	29.17 ±1.06^{a}	29.27 ±1.39^{a}	29.69 ±1.78^{a}	28.49 ±1.71^{a}	30.36 ±1.29^{a}	30.02 ±1.65^{a}	28.79 ±1.28^{a}	27.22 ±2.08^{a}	28.96 ±1.29^{a}	27.47 ±1.92^{a}	26.96 ±1.55^{a}
ΣMUFA	45.18 ±1.58^{c}	40.77 ±1.36^{bc}	41.25 ±2.14^{bc}	40.56 ±1.33^{b}	42.54 ±1.35^{bc}	42.88 ±2.03^{bc}	41.69 ±2.02^{bc}	40.51 ±1.30^{b}	40.73 ±1.74^{bc}	39.94 ±2.03^{b}	35.02 ±2.20^{a}
ΣPUFA	24.10 ±0.86^{c}	22.88 ±0.96^{bc}	21.75 ±1.66^{bc}	20.54 ±0.99^{ab}	22.33 ±1.08^{bc}	21.62 ±1.46^{bc}	21.05 ±1.96^{bc}	20.76 ±0.71^{bc}	20.98 ±1.09^{bc}	19.91 ±1.32^{ab}	17.22 ±0.89^{a}
[1]Σn-3 PUFA	16.17 ±0.49^{c}	14.82 ±0.38^{bc}	13.97 ±0.99^{bc}	13.54 ±0.74^{ab}	15.10 ±0.53^{bc}	14.52 ±0.91^{bc}	14.27 ±1.17^{bc}	14.24 ±0.53^{bc}	13.96 ±0.92^{bc}	13.35 ±0.87^{ab}	11.84 ±1.40^{a}
[2]Σn-6 PUFA	7.93 ±0.25^{b}	7.29 ±0.28^{ab}	7.78 ±0.24^{ab}	7.01 ±0.35^{ab}	7.23 ±0.64^{ab}	7.11 ±0.36^{ab}	6.78 ±0.48^{ab}	6.52 ±0.54^{ab}	7.02 ±0.35^{ab}	6.56 ±0.73^{ab}	5.39 ±0.61^{a}
Ratio n-3/n-6	2.04 ±0.21^{a}	2.00 ±0.15^{a}	1.86 ±0.37^{a}	1.99 ±0.24^{a}	2.03 ±0.19^{a}	2.03 ±0.25^{a}	2.08 ±0.33^{a}	2.18 ±0.22^{a}	2.06 ±0.17^{a}	2.04 ±0.16^{a}	2.20 ±0.41^{a}

Data represent average of triplicate analyses (mean ±STD). Values in the same row that do not share the same letters are significantly different ($P<0.05$)

[1]Σ (n-6) ≥18:2n-6, [2]Σ (n-3) ≥18:3n-3; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA, eicosapentaenoic acid (20:5 n-3); DHA, docosahexaenoic acid (22:6 n-3); ARA, arachidonic acid (20:4n-6)

**Control indicates the frozen Artemia sample was analyzed for comparing with the dried Artemia biomass*

4 DISCUSSION

4.1 Effect of different drying techniques and temperatures on drying time

Our study indicated that among three indoor drying methods, the combined microwave and conductive hot air drying resulted in faster drying as compared to the convective hot air and oven drying. These observations are in agreement with other researchers who found that combining microwave energy with convective drying can lead to considerable reductions in drying times for cooked chickpeas and soybeans (Gowen *et al*., 2007) and hairtail fish (Hu *et al*., 2013) compared to the convective drying alone. According to Nindo *et al*. (2003), drying asparagus by the combination of microwave and spouted bed drying resulted in the fastest drying rate compared to freeze drying, tray drying and spouted bed drying. Similar results were observed by Chua and Chou (2005), the intermittent microwave drying can significantly reduce drying time in comparison with convective or intermittent infrared drying, without the samples being charred; these authors found that using a suitable combination of convective-microwave drying, drying time can be shortened by as much as 42 and 31% for potato and carrot samples, respectively.

Previous investigations reported that high-moisture vegetables, fish and aquatic products are very responsive to microwave application, and absorb microwave energy quickly and efficiently (Pianroj *et al*., 2006; Darvishi *et al*., 2013), whereas hot air drying of food has a low energy efficiency and needs a lengthy drying time. Because of the low thermal conductivity of food materials, heat transfer to the inner sections of food during conventional heating is limited (McMinn *et al*., 2005). In microwave drying, the microwaves can easily penetrate into the inert dry layers to be absorbed directly by the moisture; the quick energy absorption causes rapid evaporation of water resulting in shorter drying time. Therefore, it is a rapid, more uniform and more energy-efficient technique as compared with conventional hot air drying (Wang *et al*., 2007). Schiffmann (1995) explained the efficiency of combined microwave and convective hot air drying by the fact that convective hot-air is relatively efficient in removing free water at or near the surface, whereas the unique action of microwave provides an efficient way of removing internal free and less free water. An appropriate microwave power level, used in sequence with hot-air drying prevents the samples from charring. Furthermore, Pianroj *et al*. (2006) reported that the drying process in the microwave system shows a dependence of fish surface temperature and moisture content on the radiation time and microwave power. Duan *et al*. (2010) evaluated combined microwave – hot air drying for tilapia fish fillets at microwave power from 200 to 600 W and air temperature from 40 to 50°C with constant air velocity of 1.5 m/s. Their results showed that hot air-microwave drying technology can be used for drying of fresh tilapia fillets owing to decrease in drying time and to improve quality of dried fish. Hot air drying followed by microwave drying can decrease remarkably the drying time for drying fresh tilapia fillets compared with hot air drying alone. In the present experiment, it was observed that increasing drying temperatures from 50 to 70°C resulted in a shorter drying time of *Artemia* biomass for all drying methods used. Similar observation was reported by Omodara and Olaniyan (2012), the drying rate increases with increase in temperature from 40 to 50ºC for all the African catfish samples and decreases with time. Faster drying is due to high evaporation that can drive the moisture migrating to the surface in minutes. Our results were in accordance with similar studies conducted on Tilapia (Duan *et al*., 2010) and African catfish (Omodara and Olaniyan 2012). On the other hand, in our study oven drying was found to be slower than convective HA drying, probably because the oven lacked a built-in fan for air circulation, resulting in a lower energy-efficiency for oven drying as compared to convective HA drying (Brennand 1994). In our study, the drying time was longer for sun drying due to the fluctuating temperature during the drying period, which is strongly affected by the weather conditions. Therefore, in case of sun drying, the drying period may be interrupted during rainy or cloudy days (low temperature and high relative humidity), causing the most extended drying time compared to other drying methods (Chua and Chou 2003; Akintola *et al*., 2013).

4.2 Effect of different drying techniques and temperatures on the contents of total lipids and fatty acids in dried *Artemia* biomass

Our results showed that the total lipid contents of dried *Artemia* in all drying methods were lower than in frozen *Artemia* (control). These results confirm the findings of Liou and Simpson (1989), who reported that the lipid levels of *Artemia* nauplii dried by vacuum and hot air drying were lower than in newly-hatched *Artemia*. In our study, however, significant losses of total lipids were observed in HA70, Oven50 and Oven70 and sun-dried samples when compared to the control ($P<0.05$). This indicates that loss of lipids after drying may be not only affected by drying temperatures but also by drying time. For example, oven drying at 50°C and sun drying at temperatures between 26-39°C took much longer (1320 min and 1380 min, respectively) than MWHA and HA drying (74 and 960 min, respectively). According to several authors (Chukwu 2009; Duan *et al*., 2010; Omodara and Olaniyan, 2012), drying time and temperature can be considered the most important operating parameters affecting the quality of dried products. On the other hand, some food products require several hours and others may take more than a day. Prolonging drying time (by using lower temperatures) or interrupting drying time may result in spoilage of dried products (Brennand, 1994) whereas high temperatures during drying leads to the partial destruction of the nutrients (Akintola *et al*., 2013; Hu *et al*., 2013). This was also observed in our study, where *Artemia* samples dried at higher temperatures resulted in slightly lower content of total lipids, but not significant difference ($P>0.05$). Possibly the 10°C increment of drying temperature might be insufficient to cause statistical differences. Similar results were obtained by Paleari *et al*. (2003), who reported that a decrease of fat content during processing has been shown in cured and dried products from different animal species. For sun drying, the prolonged direct incidence of sunlight may accelerate lipid oxidation, as illustrated by the lipid content in our sun-dried sample being significantly lower than the control and MWHA samples ($P<0.01$).

The fatty acid contents in the *Artemia* biomass, dried indoors with various techniques at temperatures of 50, 60 and 70°C were very similar. When comparing with the frozen *Artemia* significant differences were only found in the contents of some of the fatty acids, with the actual values showing only minor differences (Table 2). In general, the saturated fatty acids (SFA) were almost equal or slightly higher, whereas the unsaturated fatty acids (UFA) decreased when compared to the frozen sample. This can be observed in nearly all individual FA as well as in the different sums and ratios. These results are confirmed by Sampels *et al.* (2004), who reported that dried reindeer meat showed higher values of total SFA whereas total

UFA were lower compared with fresh meat. According to Mottram (1998), unsaturated fatty acids undergo oxidation more easily than SFA. Nonetheless, Liou and Simpson (1989) found that no statistical differences were recorded in the total percentage of saturated, monoenoic, dienoic, unsaturated n-3 and n-6 fatty acids between fresh *Artemia* and *Artemia* dried by freezing, vacuum or hot air drying. Furthermore, several researchers reported that the fatty acid profiles of raw, baked, broiled, gilled and microwave cooked sardines and sea bass fillets were not significantly different (Maeda *et al*., 1985; Yanar *et al*., 2007). However, in the present experiment, total MUFA, PUFA and total n-3 PUFA including EPA and DHA contents of dried samples were more affected by the drying process and temperature than total n-6 PUFA and ARA values.

Pigott and Tucker (1990) reported that a major loss of n-3 fatty acids in fish oil was observed at high temperature and that highly unsaturated fatty acids are highly susceptible to oxidative rancidity, with the development of off-flavours. As mentioned above, drying temperature and drying time caused the same effect as on total lipid content. According to Bórquez *et al.* (1997), as drying time increases, losses of n-3 fatty acids in fish protein concentrates increased in fluidized bed-drying and drying temperature had little effect (between 60 and 80°C) on n-3 fatty acid losses under drying conditions. A higher drying temperature in fluidized bed-drying with a shorter drying time would yield a higher quality of fish protein concentrates (*i.e.* with minimal rancidity). Similar results were obtained by Bórquez (2003) who found that the loss of n-3 fatty acids of fish particles increased with drying time in impingement drying, and that the drying medium temperature is the most important variable, influencing both processing time and product quality. Although n-3 and n-6 PUFA levels in conventionally cooked rainbow trout fillets were lower than in microwave-cooked fillets, the difference was not statistically significant (Unusan 2007). These results were in agreement with the present experiment, where at the same drying temperature, contents of total lipids and FA compositions in MWHA-dried samples were slightly higher than those of HA and oven drying, but where significant differences were not detected (P>0.05). Moreover, all individual fatty acid concentrations of *Artemia* dried using the three different indoor techniques revealed the same effect as with the total lipids, with no significant differences at different drying temperatures. Temperatures in the range of 50-70°C may thus be considered acceptable for drying *Artemia*. Pianroj *et al*. (2006) found that heat produced by the microwave system causes evaporation of moisture from the fish making it possible to produce high quality dried fish. The drying duration of a product could depend on the characteristics of the product as both too high and too low drying rates may spoil the product. Especially, for highly perishable products it may be necessary to dry them in a shorter time (Hii *et al*., 2012).

Overall, the fatty acid contents in the sun-dried product was significantly lower than in the frozen sample (P<0.01) except for the total SFA. When compared with the three indoor drying methods, significant differences were only found for levels of DHA, MUFA, PUFA and n-3 PUFA. Similar results were reported for the sun dried and solar dried sardine (Immaculate *et al*., 2012), the sun-dried black tiger shrimp (Akintola, *et al*., 2013). According to Anh *et al*. (2014), all analyzed total lipid and fatty acids parameters of solar-dried *Artemia* biomass differed less from fresh *Artemia* than in sun-dried samples. Moreover, both for solar and open sun drying of *Artemia* biomass, a longer drying time resulted in lower values of total lipid and fatty acids of dried products.

Alghren *et al*. (1994) considered the n-3/n-6 ratio as the most important indicator of fish lipid quality, which also reflects the quality of fish as a food. The ratios of n-3/n-6 PUFA in all dried *Artemia* samples were in the range of 1.8-2.2 and the control value was 2.0. This indicated that these drying methods did not affect this ratio. Our results are in accordance with Sampels *et al*. (2004) who reported that the n-6/n-3 ratio was not affected by the drying method. A similar result was detected by Yanar *et al*. (2007) who found that baking, grilling and microwave cooking did not change the ratio of n-3/n-6 fatty acids compared with the raw fillets of sea bass. In this study, within the temperature range of 50-70°C, a longer drying time caused lower values of total lipids and fatty acids in dried *Artemia* samples.

Overall, conductive HA drying, intermittent MWHA drying and oven drying at temperatures of 50 and 60°C could be appropriate techniques to dry *Artemia* biomass without significant loss in total lipids and fatty acids. Application of hot air and oven drying at 70°C caused higher reduction of these nutrients. Especially intermittent MWHA drying gave high quality of dried products in short drying times but it may not be suitable for large-scale application because of high initial capital investment and operating costs. Conversely, sun drying resulted in significant reductions of total lipid and fatty acid contents in dried *Artemia* but it does not need energy (fuel or electricity) for operating during drying process. Thus there is a need to find alternative drying methods both with respect to the economic aspect and product quality. According to Chua and Chou (2003), both sun and solar drying are cheap methods because they benefit from solar heat in which solar drying is a modification of sun drying, *i.e.* the sun's rays are collected inside a specially designed unit resulting in higher temperature with adequate ventilation for removal of moist air. It is likely that the use of a solar dryer can result in shorter drying time as well as higher quality product than in sun drying due to the judicious control of the radiative heat.

In the coastal areas Bac Lieu and Soc Trang provinces, several hundreds of hectares of *Artemia* cyst production areas are in operation during the dry season. Hence, future research should aim to develop appropriate techniques for solar drying and evaluate its effect on nutritional quality of dried *Artemia* biomass. Such a solution could help the farmers to salvage large amounts of live *Artemia* biomass, which is a by-product of their cyst-oriented *Artemia* ponds and convert it into feed or as ingredient in formulated feeds for shrimp, fish, livestock and poultry. This integrated production could contribute to the profitability of *Artemia* farmers' operations and thus have a positive impact on their socio-economic status in this area.

5 CONCLUSIONS

The drying time was shortest for intermittent MWHA drying and longest for sun drying. Besides, drying was faster in convective hot air than in oven drying and drying time was reduced significantly when drying temperature increased.

The conductive HA drying, intermittent MWHA drying and oven drying at temperatures of 50 and 60°C could be adequate techniques to dry *Artemia* biomass without significant loss in total lipid and fatty acids of dried *Artemia*. Particularly the intermittent MWHA drying is a promising method, which could produce high quality of dried products in short drying times.

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