Improved Quality of Dried Philippine Sandfish (*Holothuria scabra*) using a Combination of Hot-Air Drying and Solar Drying

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ABSTRACT

Traditional methods of processing and drying sandfish [Holothuria ((Metriatyla)) scabra] result in poor quality and low value products in the market. The drying process generally involves smoking and sun drying which can leave scorch marks and smoke residue, and result in inadequate drying especially during poor weather. A combination of hot air drying and solar drying (Treatment I) was compared to the traditional process of smoke drying followed by sun drying (Treatment II) to determine the effect on product quality and price. Results showed that significant shrinkage occurred regardless of the drying treatment used. Shrinkage was greater in samples subjected to the traditional process, although this was not statistically significant. Scanning electron microscopy revealed changes in muscle and collagen fibers between primary drying (hot air drying or solar drying) and secondary drying (solar drying or sun drying). Assessment of dried samples by a producer, consolidator, and exporter showed that processed sandfish dried using Treatment II had better quality and could command prices higher by 25-89% compared to Treatment I samples.

Keywords: Sandfish, sea cucumber, drying, shrinkage

INTRODUCTION

The sea cucumber known as sandfish [*Holothuria ((Metriatyla))* *scabra*] is one of the most commercially valuable tropical species that is processed into *beche-de-mer* or *trepang* (Agudo 2006). Sandfish is one of 25 species that are harvested commercially in the Philippines (Lovatelli *et. al.,* 2004; Gamboa *et. al.* 2004).

Traditional sandfish processing in the Philippines is a multi-step process that involves degutting, boiling, cleaning, smoking and sun-drying for several days (Brown *et. al.,* 2010). Boiling and cleaning may be repeated 2-3 times until the outer spicular layer of the body wall can be scrubbed off easily.

The smoking process lowers the moisture content of the body wall to about 38% wet basis or 0.61 g g-1 dry matter and is usually performed by fishers. At this stage, the boiled sandfish is still vulnerable to decay and must be dried to a stable moisture content that ensures a long shelf life. Samples obtained from consolidators or processors show that the moisture content of thoroughly dried product is about 12% wet basis or 0.14 g g-1 dry matter (Yaptenco *et al.* ,2013). The final stage of drying is usually done by sun-drying to reduce costs. However, poor weather can delay this stage and promote decay, resulting in poor quality and a low selling price. The national standard for the Philippines requires dried sandfish to have a maximum moisture content of 15% by weight (BPS-DTI 2013).

Information on processing and drying of sandfish is minimal in published literature. The knowledge gaps that need to be filled include data on grades and sizes of sea cucumber, harvesting and handling methods to minimize mechanical damage, and reliable methods of processing and drying to produce high-quality products (Lovatelli *et.al.,*2004).

Poor processing and drying methods significantly reduce the selling price of trepang. The main factors that affect selling price include species, size and moisture content. Hence, the main objective of the study was to compare traditional methods of drying sandfish to improved drying methods. Comparisons were made in terms of drying cost and product quality.

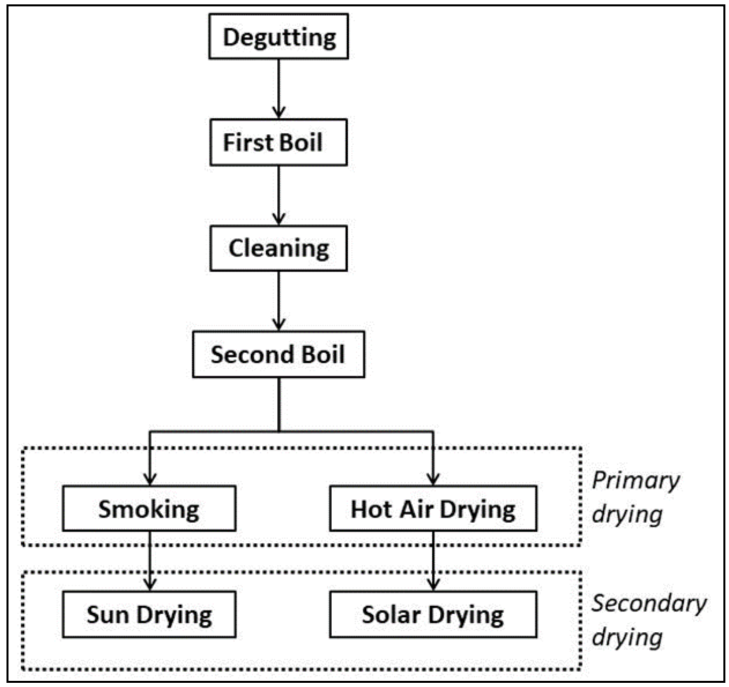

Figure 1. Process flow for producing dried sandfish

METHODOLOGY

Sample Preparation

Philippine National Standards (PNS) for sandfish specifies that only animals with a live weight of 320 g or larger can be harvested (BPS-DTI 2013). For this study, only sandfish with a live weight of 350 g or more were used; sampling sites included Lopez Jaena in Misamis Occidental province, and Coron in Palawan province. Samples were degutted by making a 1.5-cm slit at the posterior end and squeezing out the internal organs. Samples were then wrapped in polyethylene plastic bags, packed in ice and transported to the Institute of Agricultural Engineering at the University of the Philippines Los Baños, Laguna.

Cooking and Cleaning Process

The following cooking procedure was based on information provided by the National Fisheries Research & Development Institute (NFRDI) of the Bureau of Fisheries & Aquatic Resources (BFAR). Degutted samples were first immersed for 15 min in fresh water preheated to 60^{o}C; the water was then heated to boiling temperature (≈ 100^{o}C) while continuously stirring. Once the water started boiling, sandfish samples were cooked for an additional 60 min with stirring. The outer spicule layer was manually removed by scrubbing and brushing with cleaning pads and plastic brushes. A second boiling stage was carried out for another hour, followed by further cleaning until samples were free of spicules (Figure 1). A Fluke 52 II digital thermometer (Fluke Corp., Washington, USA) with a type-T thermocouple probe was used to monitor sandfish and water temperature.

Drying Treatments

Two drying treatments (referred to as Treatment I and II) were used with each treatment composed of a primary and secondary drying stage. For both treatments, samples were briefly weighed during drying using a SCALTEC-SBC 31 digital weighing scale (Denver Instruments, New York, USA). For

Treatment I, smoke drying and sun drying were used as the primary and secondary drying stages, respectively (Figure 1). Smoke drying was performed by placing boiled and cleaned samples on wire mesh and suspending them above live coals (from coconut husk and shells). Samples were turned at regular intervals to promote uniform drying during the process. Samples were then sun-dried on wire mesh from 8:00 am to 4:00 pm; during periods of poor weather (e.g. rainy days), the samples were kept in glass desiccator jars sealed with vacuum grease. Since Treatment I attempts to simulate the traditional process of drying sandfish, air temperature was not controlled during smoke drying. Correct heating was achieved by using just enough coconut waste as live coal and maintaining a sufficient distance (about 40 cm) from the heat source to avoid scorching.

Hot air drying and solar drying were used as the primary and secondary drying stages for Treatment II, respectively. For both stages of Treatment II, a prototype hybrid dryer developed by Yaptenco *et. al.* (2013) was used which could be heated using a biomass stove or solar radiation. The hybrid dryer consisted of a detachable drying chamber placed on top of a steel firebox containing the stove. When heated with biomass waste, the top panel of the firebox served as a hot plate, heating the drying chamber by natural convection. During favourable weather, the drying chamber could be detached from the firebox and positioned to catch the maximum amount of solar radiation. The top panel of the drying chamber was sloped and made of transparent plastic sheet to serve as a solar collector. For Treatment II, the firebox-heated drying chamber was used for hot air drying; a temperature of 50-60°C was maintained by manually controlling the fuel fed to the stove. The firebox was fed with biomass waste until sundown; to ensure extended drying conditions after sunset, cement blocks preheated on top of the firebox served as a thermal sink that could be used as a heat source at night. This saved on fuel and reduced the labor needed to keep the firebox lit. Once samples were semi-dry, the drying chamber was detached and used as a solar dryer for secondary drying (Figure 1). The upper limit of 60°C was based on the air temperature used by Duan *et. al.* (2010) for hot air drying; the lower limit of 50°C was selected as being the most feasible to achieve with manual feeding of fuel while keeping air temperature sufficiently elevated. Air temperatures above 60°C were avoided to prevent the development of case hardening that could slow down the drying process and lead to spoilage.

The samples were solar-dried daily from 8:00 am to 4:00 pm until the proper texture was reached. Air and sample temperatures were monitored using a Fluke 52 II digital thermometer and type-T thermocouple wire sensors. Tiny Tag Ultra 2 / Plus 2 data loggers (Omni Instruments Inc., Dundee, UK) was used to measure RH during Treatment II.

Physical Properties of Dried Sandfish

Length, width and thickness were measured for samples used in all treatments using a General Ultra digital caliper (General Tools & Instruments, New York, USA) readable to + 0.01 mm. Measurements were taken during processing of samples and at every drying stage. Shrinkage (S) was computed using Equation 1, where Do = original dimension, and Df = final dimension.

$$S = \frac{D_o - D_f}{D_o} \, x \, 100\% \qquad (1)$$

Moisture content on a dry basis (MCdb) was determined during Treatment I and II, as well as during oven drying, by drying at 100°C for 3 days; Equation 2 was used to compute for MCdb, where Wi = initial sample weight, and Wf = final sample weight.

$$MC_{db} = \frac{W_i - W_f}{W_f} \qquad (2)$$

Images of the microstructure of sandfish at different drying stages of each treatment were acquired by a S -3400N scanning electron microscope (SEM) (Hitachi High Technologies Corp., Tokyo, Japan) at the National Institute of Geological Sciences Laboratory, University of the Philippines Diliman, Quezon City. Tissue samples (5-mm cube) were cut from the following areas of the cross-section of a sample: (1) adjacent to the skin, dorsal side; (2) middle portion, and (3) near the lower portion of the ventral side.

Drying Curve of Sandfish

To generate a drying curve for processed sandfish, samples were dried at 60°C using a UNB 400 forced -convection oven (Memmert GmbH + Co. KG, Schwabach, Germany). This was based on the study by Ekpenyong and Ibok, (2012) that used a temperature range of 60-76°C for smoking catfish. Sample weight was measured using a digital weighing scale until a stable level was reached.

Moisture content (g g^{-1} dry matter) of samples was converted to a moisture ratio (*MR*) using Equation 3, where MC_t = moisture content at any time *t*, MC_e = equilibrium moisture content, and MC_o = initial moisture content. Drying was terminated when the drying rate reached 1 x 10^{-4} g g^{-1} hr^{-1} or less; MC_e. Non-linear regression was used to fit *MR* versus *t* data to the thin-layer drying Page model (Sharon *et. al.*, 2016) expressed by Equation 4, where *k* and *n* are regression constants.

$$MR = \frac{MC_t - MC_e}{MC_o - MC_e} \quad (3)$$

$$MR = \exp(-kt^n) \quad (4)$$

Statistical Analysis

Statistical analysis of data was carried out by ANOVA at the 5% level of significance using SPSS ver. 17.0 (IBM, New York, USA). Tukey's honest significant difference (HSD) test was used to determine the significance of differences between treatment means.

RESULTS AND DISCUSSION

Size of Dried Samples

Length of dried samples had a range of 140.92 – 155.74 mm with the maximum length observed in hot air-solar drying samples while the lowest was smoke-sun dried samples. It can be noted that the samples' body length range from 140-160 mm. The body length is within the matured sea cucumber length (150-170 mm) as reported in published literature (Choo, 2008, Purcell *et. al*., 2010, Purcell 2014). During primary drying (smoke drying or hot-air drying), it was observed that shrinkage was not significantly different (p<0.05) between treatments in terms of length, thickness or width (Table 1). However, after the secondary drying stage, significant differences in shrinkage (p < 0.05) were observed in terms of length and width (Table 2). Comparing the final dimensions to the original condition of the samples, the overall shrinkage had a range of 34-40% from the original body length, thickness and width of sandfish.

Table 1. Mean shrinkage (± SD) of sandfish samples measured after primary drying

METHOD	SHRINKAGE (%)		
	Length	Thickness	Width
Smoke drying	28.83^{ns}	13.05^{ns}	28.58^{ns}
Hot air drying	25.43^{ns}	18.21^{ns}	26.41^{ns}

ns = not significantly different by ANOVA at the 5% level of significance

Table 2. Mean shrinkage (± SD) of sandfish samples measured after secondary drying

METHOD	SHRINKAGE (%)		
	Length*	Thick-ness*	Width*
Smoke drying – Sun drying	39.40^{a}	36.21^{a}	38.26^{a}
Hot air drying – Solar drying	35.85^{a}	36.40^{a}	38.23^{a}

**In a column, means followed by a common letter are not significantly different by the Tukey HSD test at the 5% level of significance.*

Purcell *et. al.* (2009) observed changes in body length and weight of six species of sea cucumber *(Actinopyga echinites, A. spinea, A. palauensis, H. lessoni, Stichopus hermanni, H. whitmaei)*. For these species, the body length of the dried product was 38-60% of the original whole fresh body; in terms of weight, the dried product was 3.3-11.7% of the original fresh weight.

Drying of Boiled and Cleaned Sandfish

For Treatment I, smoke drying was completed after 24 hrs (Figure 2), where average air temperature and RH was 45.7°C and 60.3%, respectively; mean internal temperature of processed samples were 34.9°C. Samples were then subjected to sun drying until MC reached a stable value of 0.22 g g-1 dry matter. This required an additional 59 hrs of sun drying; total drying time for Treatment I was 83 hrs to reach a stable MC.

In comparison, air temperature and relative humidity during hot air drying for Treatment II was 55.1°C and 33.6%, respectively. Average internal temperature of samples during hot air drying was 42.7°C. Hot air drying was performed for about 50 hrs, followed by solar drying where a stable MC of 0.20 g g-1 dry matter was reached after 100 hrs. Total drying time for Treatment II to reach a stable MC was 150 hrs. The longer drying time for Treatment II could be due to reduced air movement during the primary drying stage, as well as indirect exposure to solar radiation during secondary drying which slowed down the drying process.

Provision of cement blocks in the hybrid dryer kept air temperature elevated for up to 8 hrs even without additional biomass fuel; during this period, the average air temperature and RH inside the hybrid dryer were 45.2°C and 35.6%, respectively.

The drying curve of processed sandfish is shown in Figure 4, where the Page model showed a good fit with R2 = 0.998. Dried sandfish is relatively stable at a moisture content of 0.12 – 0.18 g g-1 dry matter for a temperature range of 30-60°C. Moisture uptake is minimal up to a water activity of 0.6 (Yaptenco *et. al.,* 2017). To reach this moisture content, the estimated drying time at 60°C using a laboratory oven would be 90.9 – 121.8 hrs. However, using either smoke drying-sun drying (Figure 2) or hot air drying-solar drying methods (Figure 3) would also give comparable drying times.

Structural Microscopy

Inspection of the cross-sections of boiled sandfish after primary drying showed that smoke-dried

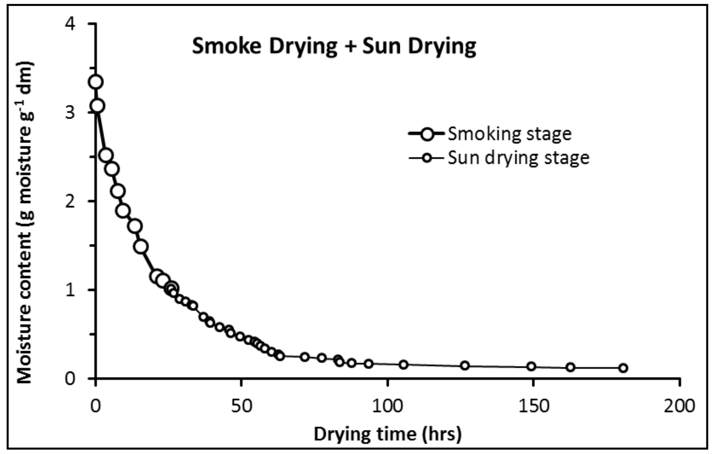

Figure 2. Drying curve of sea cucumber (*H. scabra*) samples during Treatment I

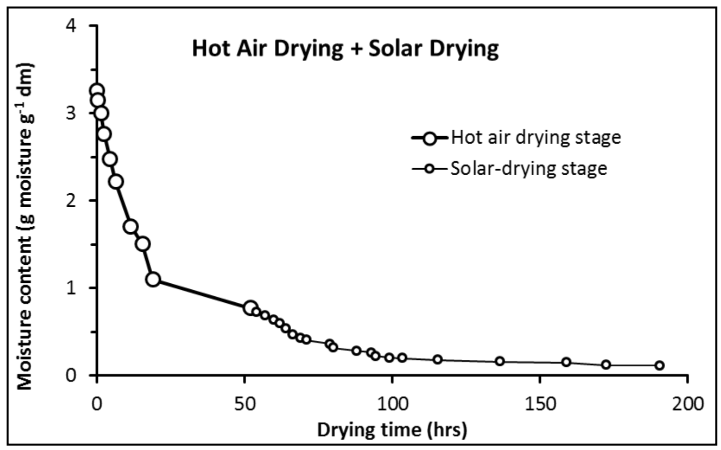

Figure 3. Drying curve of sea cucumber (*H. scabra*) samples during Treatment II

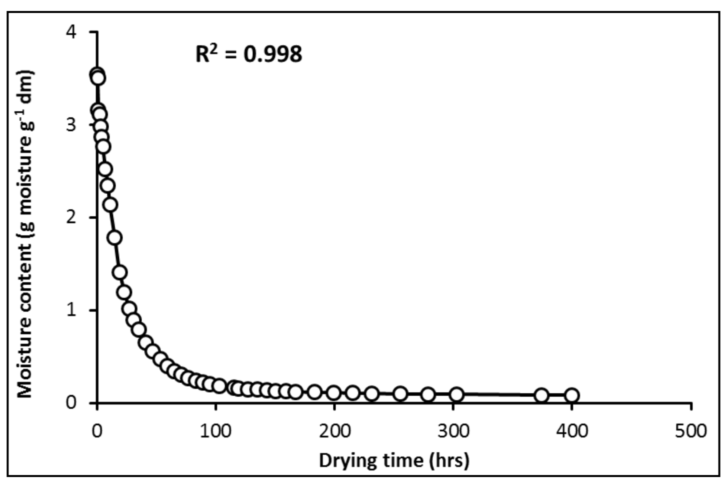

Figure 4. Drying curve of sea cucumber (*H. scabra*) at 60°C. Solid line represents the drying curve generated using the Page model (Equation 4), where k = 0.0654 and n = 0.8912.

samples formed a thick and black outer layer (Figure 5a, 5b); this layer was absent in hot air-dried samples (Figure 5c, 5d). This effect on smoke-dried samples could be due to the collapse of the outer cell membrane or uneven removal of moisture, resulting to surface hardening of the samples. Migration of inorganic salts to the surface as evaporation occurs also leads to surface hardening during the drying process (Duan *et. al.,* 2010).

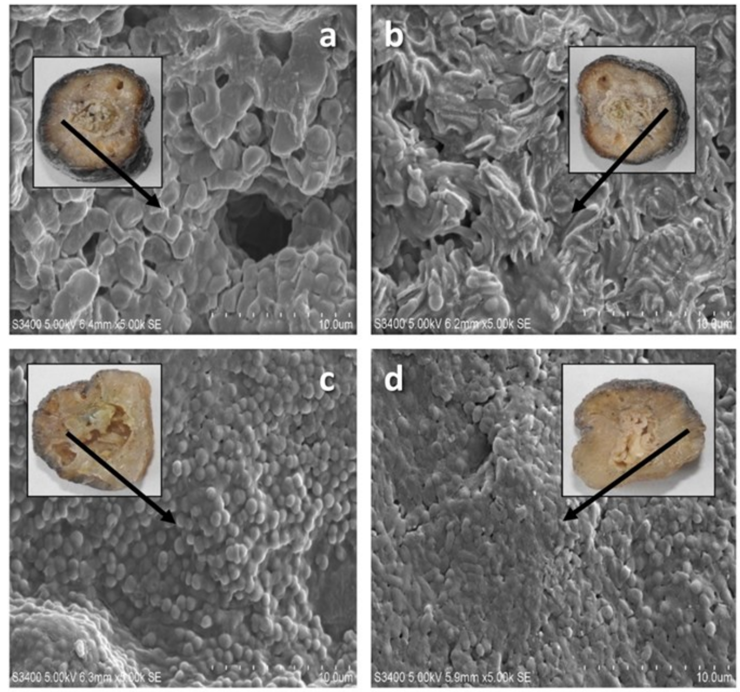

Figure 5. SEM micrographs (magnification of x5000) of tissue samples from semi-dried sandfish after smoke drying (a, b) and hot air drying (c, d).

Note: Pictures show micrographs of samples from the middle section (left column) and near the outer layer of the dorsal side (right column). Inset photos show cross-sections of semi-dried sandfish and the locations where the samples were extracted .

The cell structure examined through SEM micrographs comparing samples excised in the middle of the cross-sectional tissue sample and near the outer layer (dorsal side). Smoke-dried samples showed distorted cell membranes near the outer layer (Figure 5a, 5b) while hot air-dried samples showed a more defined cell structure (Figure 5c, 5d).

The SEM micrographs also revealed that the muscle fibers in the body wall formed spherical structures in the middle section of tissue samples from smoke-dried and hot air-dried sandfish (Figure 5a and 5c, respectively). This may be associated with voids in muscle tissue that tended to expand during drying. Hot air-dried samples showed similar structure between middle and outer layers (Figure 5c and 5d); in contrast, cell structure in smoke-dried samples showed distortions due to cellular collapse. Shrinkage was more severe in smoke-dried samples, which could lead to surface hardening of the material.

Microstructure of Fully-Dried Sandfish

SEM images at a magnification of 1200x obtained by Duan *et. al.* (2010) showed that muscle and collagen fibers of fresh sea cucumber are slender and directionally arranged. After air drying, freeze drying or microwave-freeze drying, a reticulation structure was formed with air-dried samples showing less porosity compared to freeze-dried or microwave/freeze-dried samples. Fibers also lost specific direction, regardless of the drying method.

For the present study, the structures and features present after primary drying (Figure 5) are absent after secondary drying. Inspection of SEM images (at 5000x magnification) of fully dried sandfish tissue show microstructural changes in muscle fibers, regardless of the drying treatment used. Cross -section images taken near the surface of the dorsal side (Figure 6a, 6b), middle portion (Figure 6c, 6d), and near the surface of the ventral side (Figure 6e, 6f) show that disruption, deformation and folding was present after the drying process. Structural collapse and apparent differences between drying treatments such as distorted muscle fiber (Figure 6e) could be due to moisture transport mechanism, environmental pressure, and moisture gradient or internal pressure causing cell membrane breakdown. Regardless of the drying treatment used, gelatinization or gel formation due to denaturation of muscle and collagen could result in poor fiber definition at any location in the processed samples.

Pricing of Dried Sandfish Products

Sandfish dried using Treatment II (hot air drying + solar drying) commanded higher prices compared to samples produced using Treatment I (smoke drying + sun drying) (Table 3). A study by Pangan *et. al.* (2017) also used a similar hybrid dryer for drying sandfish; the finished product was also considered as Class A, with prices reaching Ph₱5,300 kg^{-1} and Ph₱4,300 kg^{-1} for extra-large and large sizes, respectively.

Table 3. Evaluation summary of dried sea cucumber by stakeholder.

TREATMENT[z]	AVERAGE PRICE (₱)[y]			CLASSIFICATION		
	Producer	Consolidator	Exporter	Producer	Consolidator	Exporter
I	550.00	1,266.67	400.00	D	Not classified	B
II	1,000.00	2,400.00	500.00	A	A	B

[z]Treatment I – smoke drying plus sun drying; Treatment II – hot air drying plus solar drying
[y]Average price of three replicate samples

Factors that affect the selling price of dried sea cucumber, in general, include species, size, moisture content, shape, and the presence of defects (scorching, decay, cracks) (Figure 7a, 7c). The use of appropriate and cost-effective technology can promote sustainability of the enterprise and affordability of equipment, while producing good-quality products at the same time so as to be competitive in leading markets of dried sea cucumber (Figure 7b, 7d). Pangan *et. al.* (2017) showed that production of dried sandfish products could be profitable, with a positive net present value, benefit-cost ratio greater than 1, and an internal rate of return of 19.2%.

SUMMARY AND CONCLUSIONS

Sea cucumbers in the Philippines are traditionally dried by a combination of smoking and sun drying. However, the resulting quality of the finished product is often poor and selling price obtained by fishers is significantly lower compared to good-quality products. Smoke-dried samples showed a black surface layer that detracted from the quality, and could potentially slow down the drying process.

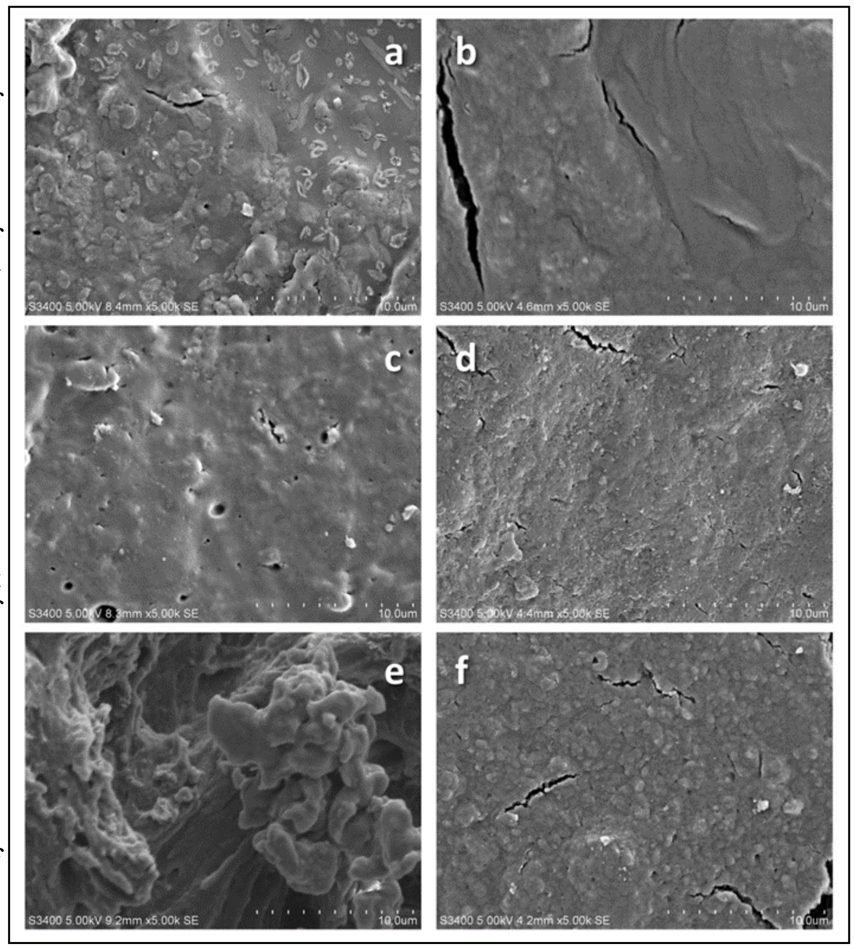

Figure 6. SEM micrographs (magnification of x5000) of fully dried sea cucumber tissue samples.

Note: Images show smoked-sun dried (a, c, e) and hot air dried-solar dried (b, d, f) samples from the outer layer of the dorsal side (a, b), the middle portion (c, d), and the lower portion of the ventral side (e, f).

Figure 7. Dried sandfish (a) produced by traditional processing and drying by artisanal fishers are typically poor in quality; (b) imported products sold in Hong Kong markets are well-cleaned and dried (photo courtesy of K.F. Yaptenco); (c) samples produced by Treatment I (smoke drying + sun drying) and (d) Treatment II (hot air drying + solar drying) are well-cleaned, and formed.

This layer was absent in samples dried using hot-air drying followed by solar drying.

The use of hot-air drying for reducing moisture content of cooked sandfish to a semi-dry condition, followed by solar drying to reach a stable moisture content, can produce Class A dried product. Harvesting of premium-size sandfish combined with hygienic cooking and cleaning practices and the use of appropriate drying methods can produce dried sandfish products that command a high price. With proper management of this coastal resource, sandfish processing can provide a sustainable source of additional income for small fishing communities and help revive the Philippine sea cucumber industry.

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