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Microbiological, chemical and nutritional quality and safety of salted cured fishery products from traditional dry fish processing plants in the Sultanate of Oman

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Abstract

Dry fish production has traditionally been practiced in the Sultanate of Oman since time immemorial and it is a thriving artisanal industry. Current production practices are very traditional lacking basic infrastructure facilities and result in products with compromised quality. This study was carried out to find the microbiological, chemical and nutritional quality of dry fish products produced in the traditional dry fish processing plants in Oman. This is the first comprehensive report of biological and chemical hazards present in Omani Dry fish products. The results showed that some of the dry fish products contained coliforms and enteric bacteria at levels beyond the permitted levels indicating the need to improve the processing hygiene standards at the plants. Hazardous pathogens such as *Salmonella* were not detected in the dry fish products. Most of the tested products showed levels of mercury, lead, and cadmium within the regulatory limits. In general, the dry fish products are safe for human consumption. Moreover, the dry fish products are highly nutritious with very high protein and fat contents. The findings of this study provide a baseline data for the quality and safety of dry fish products produced in Oman and provide opportunities for further quality improvement.

1. Introduction

Sultanate of Oman with a 3,240 km coastline is considered 100% self-sufficient in fish and fish products, with a total production of 1, 64,000 metric tons (MT) in 2010 (MAFW, 2010). The annual per capita consumption of fish is about 28 kg, which is very high compared to the world average. About one-half of the fish production is exported, mainly to neighboring GCC countries, Europe and Asia. The fisheries sector has been a historically important contributor to the Omani economy and is considered the most important non-oil source of income. In addition, it provides a valuable source of employment and a means to promote food security in the country. The sector, which affects the livelihood of approximately 200,000 individuals, is among the Sultanate of Oman's most valuable renewable resources.

Traditional fisheries is a very important component of Omani fisheries, which generated about 88% of fish produced in the country in 2010, whereas, only the remaining 12% was contributed by the industrial fisheries. Aquaculture production presently is very negligible in the country. Artisanal fishermen land their fish at many locations scattered along the coast. However, there are more than 30 centralized landing stations with satisfactory infrastructure facilities in the six coastal governorates of Musandam, Batinah, Muscat, Sharquia, Wusta, and Dhofar. Most landing centers in the remote locations operate with severely limited basic infrastructure facilities and are incapable of assuring freshness, quality, and safety of the harvested fish.

Lack of awareness about the requirements of quality, safety and the highly perishable nature of fishery products, coupled with the infrastructure limitations very often result in heavy post-harvest losses. Al-Jufaili and Opara (2006) reported a high incidence of fish losses as a major impediment to the realization of government goal towards increasing the contribution of the sector to the overall national economy. The annual loss due to the downgrading of fish in Oman has been estimated to be nearly 24 million RO (MNE, 2001).

Because of the dominance of the artisanal fishery, the present cold chain management of harvested fishery in the country is considered inadequate. Post-harvest

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losses are prevalent at all stages of the production chain. Most small and low value fish are thrown away as trash fish from the fishing vessel itself, wasting the valuable fish and polluting the environment. Estimates on the loss from trash fish discarded from commercial fishing ships range between 40-70% for demersal fishes, 5% for pelagics and 10% for the traditional sector (MNE, 2001).

The freshly landed fish may be exposed to high air temperatures up to 5 hours or more at landing centers or during retail display in unshaded areas. More than 40% of fresh fish value can be lost in just two days and these fish are usually processed into secondary fish products or discarded (Al-Jufaili and Opara, 2006). Large pelagics such as tuna, kingfish, queenfish, barracuda and large jack that are not sold within 2-3 days are commonly processed into *Maleh* (a traditional fish product that is gutted, bled, cleaned and mixed with a large quantity of sea salt and some spices for long-term preservation). It is also a common practice to prepare *maleh* at home using fish bought from markets (Al-Ghabshi, pers. comm.).

Small pelagic fish is mainly composed of sardines and mackerels. The sardines constitute about 20% of the total fish landings. They are highly perishable when left at ambient temperatures even for short periods of time, and the fish lose market demand and fetch very low prices. Fishery of sardines and mackerels are highly unpredictable and seasonal. In order to preserve the unexpected large catches of sardines and mackerels, the fishermen very often resort to salting and sun drying to prevent the spoilage or to make secondary fishery products.

Shark fishing is a significant component of Omani marine fisheries and the shark landings in 2010 was about 5300 tons (Fishery Statistics Book, 2010). About 70 species of sharks are listed as inhabiting the marine environment of Oman (Randall, 1995). Larger sharks harvested are finned and exported to the lucrative Dubai and Hong-Kong markets for dried shark fins and tails. In the past, the carcasses of large finned sharks used to be left rotting at landing sites. However, recent fisheries regulations in the country prohibit dumping of any shark part or shark waste in the sea or on shore. It also prohibits the handling, marketing or exporting of any shark part unless a license is obtained from the competent authority. Some sharks are used for making dry shark meats for domestic markets. Dried shark meat is traditionally consumed mainly by the rural Omani people.

Cephalopods and shrimps landed in the year 2010 was about 10,000 and 1000 MT, respectively. There is good demand for dried cuttlefishes and shrimp in the domestic market as well as abroad, and many fishermen are engaged in drying cuttlefish and exporting to some Asian markets.

The export of dried, salted, fermented or smoked fishery products in 2010 was only 1% (185 MT valued at 268,000 RO) of the total seafood export of the country. So, there is tremendous scope for expanding the dry fish industry in the country. The expansion of the dry fish industry will create demand for more raw materials including the discarded small and trash fishes. Thus, the dry fish industry will help reduce the fish wastage. Introducing the concepts of value addition to the dry fish industry will allow efficient utilization of trash fishes and other low value fishes.

There is a thriving traditional salted dry fish industry in the country. The dry fish production plants are scattered around the most remote locations of the six coastal governorates of Musandam, Batinah, Muscat, Sharquia, Wusta, and Dhofar. We have located and identified about 30 dry fish processing plants in the all the six regions, and most of them are concentrated in the coastal villages of the Wusta and Sharquia regions. All the dry fish production facilities are very small traditional operational units, housed in temporary open sheds and lack most of the basic infrastructural requirements of a fish processing plant. The raw materials used in the production are usually very low quality fish, which has, very often, been subjected to severe time-temperature abuse before it is processed and dried.

The production and processing conditions in the plant are very primitive and the plant staff is neither aware nor trained in any requirements of good manufacturing practice (GMP). The plants lack basic hygiene standards. The facilities have free access to insects, rodents, and other animals. Dust, sand, hazardous chemicals, pathogens and pollutants can easily contaminate the products. The nature of these facilities and operation does not allow standard sanitary operating procedures carried out in the plants. The color, texture, and appearance of the products are highly unpredictable. Consequently, the quality and safety of the final product cannot be assured. In fact, information on the quality and safety of the dry salted fishery products produced and marketed in the country is completely lacking. This study was undertaken to survey and analyze various salted dry fish products processed and produced by the traditional dry fish plants located in all the six regions of Oman.

2. Materials and methods

2.1 Sampling

Dry fish samples were collected from different dry fish processing plants in different remote locations in the country. The products were collected in clean plastic bags from the freshly produced lots and brought to the laboratory for analysis. At least ten whole dry fish or fillet samples were collected from each processing facility and transported in clean sampling bags (Whirl-PakA®) to the laboratory for analysis.

2.2 Microbiological analyses

For each fish species, five dried samples were analyzed in the microbiology laboratory of the Fishery Quality Control Center. Muscle tissue samples of 10 g from each fish was aseptically cut out and transferred to stomacher bags containing 90 ml of buffered peptone water (BPW) solution (Oxoid, Hampshire, UK). The tissues were stomached for 30 s in a stomacher 400 (Seward, UK).

Appropriate dilutions of the dried fish samples in 0.1 gm aliquots were surface plated in duplicate on the following types of media for detection or enumeration of bacteria or yeast-mold (BAM, 1995). The microbiological media and incubation conditions used for enumeration of microorganisms were plate count agar (PCA) for total plate count (APC) (at 30±1°C, 24 h). The count of coliform group bacteria was determined on violet red bile agar (VRBA) (30±1°C 24 h) (BAM, 1995).

Presence of *Escherichia coli* was determined on tryptone bile x-glucuronide medium (TBX) (BAM, 1995). Baird Parker agar (BP) was used for counting *Staphylococcus aureus* (37±1°C 24-48 h) (BAM, 1995). *Salmonella* was detected on Xylose Lysine Deoxycholate agar (XLD) (BAM, 1995). Detection of *Listeria* was carried out using PALCAM agar (BAM, 1995). Yeast and mold were enumerated on oxytetracycline-glucose-yeast extract agar (OGYE) (BAM, 1995). All culture media were purchased from Oxoid (Hampshire, UK). Readymade selective and chromogenic plates, Compact Dry ETB and Compact Dry ETC (HyServe GmbH and Co. KG, Uffing, Germany), were used for the detection and enumeration of for *Enterobacteriaceae* and *Enterococcus*, respectively following the manufacturer's instructions.

2.3 Heavy metals and histamine analyses

Ten dried fish samples from each fish species were used in the heavy metal analysis. Determination of cadmium and lead was performed with ICP–OES (inductively coupled plasma-optical emission spectrometer, Spectro Analytical Instruments, Kleve, Germany) equipped with an ultrasonic nebulizer (Varian, USA). The instrument detection limits on the ICP–OES was 0.01 mg kg^{-1} for cadmium and 0.02 mg kg^{-1} for lead. Samples were digested using microwave digestion system (Milestone ETHOS PLUS, Italy) equipped with TFM closed vessels. The power system used with the focused microwave apparatus provides continuous microwave emission at each power level. The system is a closed vessel microwave apparatus and equipped with a fume extraction system.

For each sample, 2.5 g of tissue was weighed and placed in a Teflon digestion vessel and 5 ml of concentrated (65%) nitric acid (HNO_3) and 1 ml of (30%) hydrogen peroxide (H_2O_2) were added. The sample in the vessel containing concentrated nitric acid and hydrogen peroxide was then digested at 25–180°C for 30 min with 1000 W power followed by further digestion at 180°C for 15 min with 1000 W power in a microwave. The digested samples were made up to 25 mL with milliQ water in pre-acid washed standard flasks.

High purity, deionized water purified with a MilliQ water purification system (MilliQ, Millipore, USA) was used for the preparation of reagents and standards. High quality concentrated (65% W/v) nitric acid (Merck, Darmstadt, Germany) and 35% (W/v) hydrogen peroxide (Riedel-de Haen, Seelze, Germany) were used. The standard solutions for calibration were prepared from a stock solution of 1000 mg/l by successive dilutions with 1.5% nitric acid. The standards were diluted appropriately and used to calibrate the ICP–OES. Calibration standards of cadmium and lead were purchased from Merck, Germany.

Total mercury was analyzed using Direct Mercury Analyser (DMA-80). Briefly, 0.1 g of the tissue was weighed accurately in sample boat and the total mercury was determined using Direct Mercury Analyser (DMA-80) without further sample preparation.

All the samples were taken in triplicates and all measurements were run in triplicates for standard and samples. Metal concentrations were calculated and expressed in mg kg^{-1} wet weight.

The histamine analysis was performed according to Al-Busaidi, Yesudhason, Al-Falahi, *et al*. (2011). The analysis was performed using a Waters Alliance High-Pressure Liquid Chromatography System (HPLC) model 2690 equipped with a quaternary pump, an online degasser and an injection valve with a loop capacity of 20 µl. The detector used was a Scanning Fluorescence Detector model 474 with a 330 nm excitation and 430 nm emission wavelengths. The histamine compound was determined using a reverse phase Shodex Asahipak

column model ODP-50 (150 x 4.6 mm). The isocratic mobile phase (18:82) consisted of acetonitrile (Sigma, 99.9%) and 50 mM Sodium tetraborate (Sigma, 99%) aqueous solution containing 1 mM O-phtal-aldehyde (OPA) (GR for fluorometry, Kiran light laboratory) and 1mM NAC (N-Acetyl-l-cysteine) was used at a flow rate of 0.5 mL/min. The histamine peaks were integrated and calculated with Empower software.

2.4 Proximate analyses

The proximate compositions were assayed as described by AOAC (2005). All chemicals used were of analytical grade and supplied by Sigma Co. (St. Louis, USA). Water activity (a_w) was measured with the a_w measuring system (Novasina ms1, Switzerland) according to manufacturer's instructions. Each analysis was carried out in triplicates.

3. Results and discussion

This study is the first report of the quality of cured fishery products in the Sultanate of Oman through a comprehensive national survey of dry fish processing plants in the country. Detailed investigations on the microbial and chemical contaminants and proximate composition of cured fishery products were carried out.

The quality and safety of fish and fishery products including dried and cured fishery products in Oman is controlled by the National Fishery Quality Control Regulation 12/2009. The microbiological and chemical standards and limits reported in this study are based on the Fishery Quality Control Regulation (Sultanate of Oman) 12/2009, the European Commission Regulation (EC) No 2073/2005: microbiological criteria for foodstuffs and the European Commission Regulation (EC) No 1881/2006: setting maximum levels for certain contaminants in foodstuffs.

3.1 Microbiological quality of dry fish products

The results of microbiological analysis of the salted and cured fish products from different dry fish processing plants are summarized in Table 1. The APC for all products produced in the dry fish plants did not exceed the regulatory limit of 1 x 10^5 CFU/g. This is expected considering the low water content and water activity of dry fish products. Research carried out in our own lab earlier has indicated that the total plate count of bacteria in dried shark can be kept low by drying the fish to the optimum moisture content and water activity (Al-Ghabshi *et al*., 2012). Only the dry cuttlefish ink samples showed a value of 1.74 x 10^5 exceeding the regulatory limit. This product is very rarely found in the markets.

The coliform counts were high in dry shark, anchovy, sardine, cuttlefish ink, and fermented sailfish. High counts of *Enterococcus* were obtained in several different dry fishery products such as shark sandwich, cuttlefish, cuttlefish ink, anchovy, catfish, queenfish and maldive fish and fermented products such as sailfish and kawakawa. The count of *E. coli* exceeded the regulatory limit in one sample of dry shark and one sample of dry sailfish. The yeast and mold counts were high in dry cuttlefish ink, sardine, and fermented sailfish. The count of *Enterobacteriaceae* was more in dry cuttlefish ink and fermented sailfish. *Listeria* spp. was detected in samples of dry shark, catfish, queenfish, and anchovy. *Salmonella* was not detected in dry fish products tested from any dry fish plants in the study.

The higher counts of enteric bacteria and coliforms detected in some products may be attributed to the unhygienic processing and low quality of processing water used at the traditional dry fish plants. Most dry fish plants have minimal access to potable water and there is lack of basic processing infrastructure that might have led to unhygienic processing of fish before and after drying.

3.2 Chemical quality of dry fish products

Chemical analyses for heavy metals showed that values of average mercury levels in various dry fish products fall within regulatory limits. The average mercury levels in various dry fish products sampled from dry fish processing plants are summarized in Table 2. The results showed that shark sandwich, dried shark fillet, and queenfish samples had highest average mercury content, but, within the permitted levels.

Table 2. Average mercury levels in dry fish products

Products	Mercury	
	Average levels (mg kg^{-1})*	S.D
Dry shark	0.6324	0.1009
Dry shark fin	0.0580	0.0016
Dry shark sandwich	0.8118	0.0787
Dry sardine	0.0102	0.0007
Dry silver belly	0.0048	0.0016
Dry queenfish	0.6058	0.0668
Dry catfish	0.0169	0.0010
Salt	0.0066	0.0021

* The regulatory limit is 1 mg kg^{-1}.

Mercury levels exceeded the regulatory limit of 1 mg kg^{-1} only in 2.7% of the dry shark samples, 3.2% of the shark sandwich samples and 1.4% of the queenfish samples tested. Those few samples exceeding the regulatory limits originated from large individual fishes

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Table 1. Product-wise microbiological analyses of dry fish from different dry fish plants

Products	APC (CFU/g)	Coliforms (CFU/g)	Yeast and mold (CFU/g)	ETB (CFU/g)	ETC (CFU/g)	*S. aureus* (CFU/g)	*E. coli* (CFU/g)	*Listeria* spp. (CFU/25 g)	*Salmonella* spp. (CFU/25 g)
Dry shark	1.56×10^3	14*	42	ND	151	ND	6	Present*	ND
Dry shark without skin	1.38×10^2	ND	10	ND	ND	1.82×10^2	17*	ND	ND
Dry shark sandwich	2.47×10^3	ND	29	ND	2.90×10^3*	1.13×10^2	ND	ND	ND
Dry shark fins	77	9	< 4	7	13	8.00×10^2	ND	ND	ND
Dry cuttlefish	1.62×10^3	ND	7.87×10^2	ND	5.36×10^2*	6.16×10^2	ND	ND	ND
Dry cuttlefish ink	1.74×10^5*	1.60×10^5*	1.4×10^5*	1.45×10^3*	2.5×10^5*	3.34×10^3	ND	ND	ND
Dry anchovy	8.55×10^4	2.32×10^2*	30	74	98*	2.13×10^3	ND	Present*	ND
Dry catfish	196	ND	11	ND	1.50×10^2*	100	ND	Present*	ND
Dry queenfish	322	ND	655	ND	1.50×10^2*	ND	ND	Present*	ND
Dry sardine	377	100*	1.2×10^4*	ND	ND	9	ND	ND	ND
Dry Shrimp	3.69×10^4	ND	99	ND	10	1.36×10^2	ND	ND	ND
Dry white sardine	3.00×10^2	ND	10	ND	ND	100	ND	ND	ND
Dry silver belly	1.51×10^2	ND	4	ND	4	7	ND	ND	ND
Dry Maldives fish	ND	ND	2.85×10^2	ND	8.50×10^2*	< 4	ND	ND	ND
Fermented queenfish	1.50×10^2	ND	2.41×10^2	ND	ND	5	ND	ND	ND
Fermented sailfish	76	1.44×10^3*	3.00×10^3*	8.30×10^2*	1.45* $\times 10^2$	20	1.10×10^2*	ND	ND
Fermented long tail tuna	3.30×10^3	ND	1.64×10^2	ND	4	10	ND	ND	ND
Fermented kawakawa	4	ND	4	ND	1.59×10^2*	ND	ND	ND	ND
Fermented long tail tuna	100	ND	32	ND	9	ND	ND	ND	ND

* Values above the regulatory limit; APC (Aerobic plate count); ETB (Enterobacteriaceae); ETC (Enterococcus); ND (Not detect=< 1); Present **(>1)**

of more than one-meter length. However, mercury content in none of the other dry fish products tested exceeded the permitted regulatory limit. (Al-Busaidi, Yesudhason, Mughairi *et al.,* 2011) reported that the mercury levels in fresh and frozen fishery products in Oman did not exceed the permitted regulatory limits. It should be noted that their findings are in fresh and frozen fishery products and did not include sharks.

Major factors contributing to the bioaccumulation of methylmercury in aquatic species are the levels of environmental contamination and the predatory nature and lifespan of the aquatic species (Mozaffarian, 2006). Larger species such as shark and swordfish are predatory, occupy high in the food chain and live longer. These species naturally bioaccumulate higher tissue concentrations of mercury, while smaller or shorter-lived species such as shellfish, sardines, and soles have very low concentrations (USEPA, 2013). Our finding underscores the need to regulate harvesting and processing of larger sharks, and for proposing guidelines on limiting weekly intake of dried shark meat originating from large sized sharks. This will have the added benefit of indirectly supporting the national and international efforts in conserving the shark species.

Dry shark products were also tested for the levels of lead and cadmium. The mean levels of lead in dry shark and shark sandwich did not exceed the regulatory limit of 0.3 mg kg^{-1} (Table 3). Similarly, the mean cadmium levels in dry shark samples did not exceed the regulatory limit of 0.05 mg kg^{-1}. However, the mean value in shark sandwich exceeded the regulatory limit (Table 3). Earlier studies on the lead and cadmium in the fresh and frozen fish products of Oman have found that mean lead content varied between 0.029 and 0.196 mg kg^{-1} and mean cadmium levels ranged from 0.0049 to 0.036 mg kg^{-1} (Al -Busaidi, Yesudhason, Mughairi, *et al*., 2011). However, this study is the first report of the heavy metals present in the dry fish products produced in Oman. Since the salt used in dry fish processing is usually obtained by concentrating seawater in salt pans, it may be a source of heavy metal contamination in dry fish products.

Lead and cadmium are usually present at significant levels in water systems and may possibly bioaccumulate in marine fish species because fish drinks a significant amount of seawater (Zhou *et al*., 2008). However, several studies have shown that fish flesh muscle generally bioaccumulates lesser metals compared to the other fish organs (Schlenk and Benson, 2001; Altındağ and Yiğit, 2005; Uysal *et al*., 2008). The sharks used in most dry fish plants are often large-sized measuring more than one-meter length. It has been observed that cadmium levels in fish usually increase with age (WHO, 1992). These factors might have contributed to the higher levels of cadmium in shark sandwich samples.

Lead and cadmium are trace elements which, because they serve no known useful purpose in the body of any living organism, have serious and varied adverse effects. Lead is a neurotoxin that causes behavioral deficits in vertebrates (Weber *et al*., 1997) and can cause decreases in survival, growth rates, learning, and metabolism (Eisler, 1988). Cadmium is highly toxic to various organs such as bones, brain, kidney and nervous system. Research has shown that cadmium can cause long-term toxic effects and accumulates in fish (Nriagu and Sprague, 1987; Suresh *et al*., 1993) and has unequivocally supported the toxic effects on human health (ATSDR, 1993, 2008).

Histamine levels in all products were below the regulatory level of 200 mg kg^{-1} (Table 4). However, some anchovy samples were found to have histamine levels above 100 ppm, indicating that the dried anchovy products may have been temperature abused before the products were processed. The dried anchovy samples had highest levels of histamine averaging about 124 ppm, followed by dried sardine. Certain species of bacteria such as members of *Enterobacteriaceae* can use the enzyme histidine decarboxylase to convert the fish tissue histidine to histamine during growth in the fish tissue (Frank, 1985; Lehane and Olley, 2000).

Growth of histamine forming bacteria is more rapid at high temperatures (e.g., 20°C or higher) than at low temperatures (e.g., 7.0°C) (Ababouch *et al*., 1991; Kim *et al*., 2001), and once histamine is produced, it cannot be eliminated by heat. It should be noted that most of the raw materials used at the dry fish plants are temperature abused and are prone to the activity of

Table 3. Average lead levels in dry fish products

Products	Lead*		Cadmium **	
	Average level (mg kg^{-1})	S.D	Average level (mg kg^{-1})	S.D
Dry shark	0.1640	0.0132	0.0430	0.0028
Dry shark sandwich	0.1266	0.0010	0.1273	0.0029

* The regulatory limit of Lead is 0.3 mg kg^{-1}; ** The regulatory limit of Cadmium 0.05 mg kg^{-1}.

Table 4. Average histamine levels in dry fish products

Products	Histamine	
	Average levels (mg kg^{-1})	S.D
Dry silver belly	3.185	0.2
Dry anchovy	132.77	12.87
Dry shrimps	0.36	0.02
Dry Sardine	28.81	0.85
Dry queenfish	3.59	0.2

* The regulatory limit for dry fish products is 200 mg kg-1.

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Table 5. Proximate composition of dry fish products

Products	Proximate composition											
	Protein (%)	S.D	Fat (%)	SD	Ash	SD	Salt	SD	pH	SD	Water activity	SD
Dry shark	70.49	1.28	12.40	0.93	12.73	0.33	7.37	0.34	7.20	0.01	0.59	0.01
Dry shark sandwich	41.99	0.62	7.90	1.48	15.50	0.11	11.23	0.12	8.50	0.01	0.66	0.01
Dry shark without skin	58.19	0.77	9.73	0.49	15.26	0.51	9.31	0.33	7.78	0.01	0.65	0.00
Dry queenfish	37.41	0.85	5.44	0.65	22.57	1.05	15.10	0.42	5.66	0.01	0.69	0.01
Dry shark fin	62.62	1.88	7.78	1.34	20.80	2.25	2.31	0.11	7.81	0.01	0.69	0.00
Fermented long tail tuna	45.66	0.77	5.54	0.84	19.85	0.41	13.36	0.49	5.44	0.04	0.72	0.01
Fermented sailfish	25.03	0.63	7.87	0.29	18.45	0.22	12.28	0.11	5.35	0.02	0.73	0.01
Fermented queenfish	24.53	0.61	8.80	0.10	19.54	0.22	12.10	0.00	5.61	0.01	0.72	0.01
Fermented Kawakawa	53.12	2.31	8.78	0.26	19.02	0.22	13.70	0.46	5.00	0.02	0.73	0.00

histamine forming bacteria. This can possibly pose a histamine health hazard in dry fish products such as dried anchovies and tuna. It has been reported that at least some of the histamine-forming bacteria are halotolerant or halophilic (Tsai *et al*., 2006; Kuda and Miyawaki, 2010) and some are more capable of producing histamine at elevated acidity (low pH). As a result, histamine formation is possible during processes such as brining, salting, smoking, drying, fermenting, and pickling until the product is fully shelf-stable. Although our results show that dry fish products contain histamine levels within the regulatory limits and are safe for human consumption, it is essential that fresh raw material fish, which are not subjected to temperature abuse, should be used in dry fish processing.

The results of the proximate analysis of different dry fish products are given in Table 5. Proximate analyses of the dry fish products showed a wide range of 24 - 70% protein content in different products. The dried shark had the maximum protein content of about 70%. The dried shark also had the highest fat content of 12.4%. Obviously, dry shark products are an excellent good source of dietary protein and fat compared to other dry fish products tested. Dry shark products had a measured water activity level of 0.59, showing that these products are sufficiently dried and are able to prevent the growth of hazardous microorganisms. The water activity is a very reliable indicator of the microorganisms' growth and spoilage of the dry fish products (Troller and Christian, 1978).

4. Conclusion

In conclusion, our study shows that the dry fish products produced in the Sultanate of Oman are generally safe for human consumption. However, the hygiene and processing methods of dry fish products produced at the traditional dry fish processing plants in Oman need to be improved significantly to assure best quality products are produced. Several dry fish products showed microbial levels exceeding the regulatory limits and the detection of coliforms and *Listeria* spp. in some products points to the deficiency in the supply of good quality processing water and the urgent need to improve the hygienic standards of the processing plants. In addition, the quality of raw material fish the salt used in the processing needs to be ensured. Imposing strict regulatory standards by limiting the size of sharks used in processing dry shark meat will be very practical in reducing the mercury, lead and cadmium content in dry fish products. The findings of this study have prompted concerted action and support activities by the Government regulatory agencies to improve the hygiene and processing standards of the traditional dry fish processing plants in the Sultanate of Oman.

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