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Production and characterization of Solar Sea salt in La Union, Philippines

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Abstract

The Philippine salt industry has declined due to various factors such as climate change, age-old laborious production methods, and changes in livelihood preferences. To jumpstart the revival of the salt industry in the province of La Union, a small-scale salt production process for coastal communities was developed using solar evaporation of seawater on the HDPE platform. The quality of seawater and the produced solar sea salt were determined based on physicochemical analysis, microbial and heavy metal contamination tests and salt yield. The study used four treatments based on the volume of seawater poured into the HDPE platform: T1, 100 li; T2, 200 li; T3, 300 li; T4, 400 li. The study was conducted in a Randomized Complete Block Design. Data were analyzed with ANOVA and Duncan Multiple Test for further test of significance using SPSS version 23. The salinity of seawater, taken at a depth of 0.59 meters, was 35-37 ppt, the water temperature was 29.1 - 31.54 ^{0}C, and the pH was 8.21 - 8.03. The solar drying to produce sea salt took 7-19 days, depending on seawater quantity, and the highest yield was attained in T3 with three monthly production cycles. The NaCl content of produced sea salt ranged from 81.93±0.87 - 82.57±0.20 %, and Iodine (I) content of 46.03±0.94 - 48.16±1.96 mg/kg. Inorganic arsenic (i-As) was in a range of 0.075±0.75- 76.81±1.91 µg/g, and lead (Pb) content from 9.07±0.71 - 9.41±0.48 mg/kg. *Salmonella* was not detected, while *E. coli,* and *S. aureus* were within the microbiological limits for the food-grade product.

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Introduction

Salt is one of the oldest commodities produced, traded, and consumed in the Philippines. Before colonial intervention, there existed a long tradition of indigenous salt manufacture. The country's salt output was almost self-sufficient at one point. Large salt producers from the provinces of Bulacan, Pangasinan, Occidental Mindoro, and Cavite could supply 85% of the country's annual salt consumption in the early 1990s, with imports accounting for the remaining 15%. However, by the year 2000, the supply had been significantly reduced due to various challenges. Changes in weather patterns caused by climate change have harmed the Philippines' salt industry, which relies heavily on the natural process of sun evaporation. Salt imports increased as domestic production fell. Only 10% of the country's salt is produced domestically, with the remaining 90% imported from other major salt-producing countries such as Australia and China. The current status of the Philippine salt sector is far from what it previously was. This means that the declining salt business must be revitalized.

While the potential of the salt industry is huge because of its universal need, what ultimately doomed the salt industry is not only due to climate change, but also to salt producers' reliance on age-old laborious production method, changes of preference in livelihood, and policies on salt production (Republic Act No. 8172, or the Act for Salt Iodization Nationwide (ASIN). These factors combined have badly contributed to the continuous decline of the salt industry and the country's dependence on more imports to keep up with local demands. Large salt producers from Las Pinas, Cavite, and Bulacan were forced to close down or convert their areas into other profitable avenues such as fishponds, and residential, or commercial properties. Based on the recent Value Chain Analysis of Salt Training facilitated by DOST-ICIEERD on March 18-19, 2021, salt production areas in Region 1 were found in Province of Pangasinan (Anda, Bolinao, Dasol, Infanta and San Fabian), Province of Ilocos Sur (Magsingal, San Vicente, Cabugao, Sta. Maria and Candon) and Province of Ilocos Norte (Burgos and Pasuquin) and none in the Province of La Union.

The Province of La Union, especially the municipalities of Balaoan, San Fernando, and Sto. Tomas was once involved in the salt-making industry from the 1970s to the early 1990s, using traditional sea salt production methods such as solar evaporation and cooking through boiling concentrated seawater. Based on the preliminary survey (personal interview) of the local community in selected barangays in each municipality, the sudden loss of traditional salt-making was due to the conversion of salt ponds to aquaculture, the long process and laborious salt-making method, and lastly, the rise of the opening of beach resorts that changed the employment status of the community.

This study was conducted to produce sea salt through solar evaporation in a high-density polyethylene platform and characterize its properties. Balaoan, La Union, a pristine coastal community facing the South China Sea, was chosen as a pilot testing area for sea salt production to jumpstart the revival of the salt industry in La Union and help decrease the country's importation of salt.

This project aims to simplify sea salt production to help the local community, especially the fisher folks, to have additional livelihood with the support/cooperation of the different government and non-government institutions. Specifically, it aimed to evaluate the physicochemical properties of seawater used in the production of sea salt, and determine the drying/evaporation period to produce sea salt at different volumes of seawater; the yield of solar salt produced in HDPE platform and determined the quality based on food-grade standards.

Materials and methods

Production site and set-up

The solar sea salt production was done at the coastal waters, beachside, at the DMMMSU-NLUC-FRTI compound, Paraoir, Balaoan, La Union, Philippines. The area has clean/clear seawater with diverse aquatic species such as seagrass, seaweeds, sea cucumber, sea urchins, and finfishes. The salinity of the seawater in the area ranges from 35-37 ppt, which depends on the season (dry and wet).

The coastal area is exposed to direct sunlight and wind movement, thus adding to the suitability of the area to produce solar salt through the evaporation method.

Twelve (12) rectangular HDPE plastic platforms were used in this study, which are collapsible (can be uninstalled if the rainy season comes). Each HDPE rectangular platform has dimensions of 5 m, length, 1 m width, and 0.25 m depth. There were four treatments using the different volumes of seawater, and replicated three times: Treatment 1 (100 liters), Treatment 2 (200 liters), Treatment 3 (300 liters) and Treatment 4 (400 liters). The HDPE platforms were laid out in a Randomized Complete Block Design (RCBD).

Production process

The production of solar sea salt was carried out by collecting seawater directly from the coastal waters using pails. The collected seawater was filtered using double muslin cloth before filling the HDPE platform and exposed to solar drying.

Harvesting of salt was done once there were white crystals of salt that appeared. The collection of salt was done by using a modified bamboo rake. Collected sea salt was placed in a bamboo woven basket to drain the liquid from the harvested salt. The coarse salt harvested was stored in a temporary warehouse for future evaluation and processing.

Nutrients/minerals, heavy metals and microbial analysis of solar sea salt

The solar salt samples were subjected to nutrient and mineral analysis following the AOAC, 2000. Five hundred (500) grams of solar sea salt samples from each treatment in triplicate were weighed and brought to DOST-ITDI for nutrient/mineral and Heavy metals analyses (inorganic chemistry division) and microbial analysis (microbiology division/laboratory).

Test for nutrient/mineral analysis includes the Sodium Chloride (NaCl) level, moisture, water insoluble, magnesium, sulfate, acid insoluble and iodine. Heavy metals analysis included arsenic, cadmium, lead and mercury. Test for microbial analysis contamination included aerobic plate count, yeast and mold, total coliform, *E.coli, Salmonella* and *S. aureus*.

Statistical analysis

Data were analyzed with ANOVA and any difference among the treatment's means was further subjected to Duncan Multiple Test using SPSS version 23.

Results and discussion

Water quality assessment

Table 1 presents the physicochemical characteristics of seawater used to produce solar sea salt. The salinity of seawater was 35-37 ppt, the water temperature was 29.1-31.54 C, and the pH was 8.21-8.03. The seawater was taken from areas at a mean depth of 0.59±0.11 meters.

Table 1. Physicochemical properties of seawaters used in the production of sea salt in Paraoir, Balaoan, La Union.

Parameters	Paraoir, Balaoan
Salinity (ppt)	35 - 37
Water Temperature (°C)	29.1 - 31.54
pH	8.21 - 8.03
Depth (m)	0.50 – 0.66

One primary consideration in the production of salt is the seawater's concentration or level of salinity. The measured salinity in seawater used to produce sea salt in the HDPE platform was low compared to the traditional sea salt making in ponds, which has a salinity range from 75-80 ppt. The higher salinity in the traditional production of sea salt in ponds is achieved by passing/flowing seawater to a series of elevated ponds, from the reservoir to evaporation, and finally to the crystallization ponds. This technique significantly raises the salinity of saltwater, doubling the production of sea salt. However, the salinity of 35-37 ppt is quite good/suitable for making sea salt with a production projection of 35-37 g of salt for every liter of seawater.

Heavy metal in seawater

The heavy metal contamination in sediments and coastal waters in Paraoir, Balaoan, La Union are presented in Table 2. Heavy metal concentrations in water were <0.008 mg/L, <0.001 mg/L, <0.005 mg/L, and <0.002 mg/L for i-As, Cd, Pb, and Hg, respectively. Heavy metal concentrations in sediments were 5.2 mg/kg inorganic arsenic (i-As), 3.15 mg/kg Cadmium (Cd), and 27.5 mg/kg Lead (Pb). Mercury (Hg) in sediments was not detected.

Based on the analysis results for water, all heavy metal concentrations passed the standards set by the Department of Environment and Natural Resources (DENR) - Environmental Management Bureau (EMB) Administrative Order NO. 34 series of 1990 directives for class SC waters. However, the analysis results for sediments at two seawater collection areas did not pass the DENR standards directive for the SC class of water. Class SC is coastal and marine waters intended to propagate and grow fish and other aquatic resources for commercial and sustenance fishing.

Potential toxicity of heavy metals such as i–As, Cd, Pb, and Hg, rank among the priority metals that are of public health significance and are usually monitored in the water column and surface sediments in marine and freshwater systems in the Philippines (Olivares *et al.*, 2019). Once detected in the coastal and marine environments, sources predominantly are from industrial, agricultural, and hydrocarbon-related activities, scrap metal recycling, cement plants, commercial ports, and sewage, these contaminants accumulate in sediments and soils. Thus, heavy metal concentrations in coastal areas around shipyards, ports, and industrial sites with refineries, smelters, and milling facilities, often far exceed their heavy metal background values or standard limits that can be toxic (Besada *et al.*, 2009).

Table 2. Heavy metals in seawater in DMMMSU-NLUC-FRTI, Paraoir, Balaoan based from the dissertation of A. J. Tadeo (2020, unpublished).

Culture area	Surface water samples				Sediment samples			
	i-As, mg/l	Cd, mg/l	Pb, mg/l	Hg, mg/l	i-As, mg/kg	Cd, mg/kg	Pb, mg/kg	Hg, mg/kg
Paraoir	<0.008	<0.001	<0.005	<0.002	5.2	3.15	27.5	ND
Method of Analysis	ICP-OES	ICP-OES	ICP-OES	Manual cold vapor AAS	ICP-OES	Flame AAS	Flame AAS	Manual cold vapor AAS
DENR Standard (Effluent)	0.02	0.005	0.01	0.005	0.02	0.005	0.01	0.005

ND = Not Determined

ICP-OES = Inductively Coupled Plasma – Optical Emission Spectroscopy

ASS = Atomic Absorption Spectroscopy

Table 3. Production of solar sea salt at different volumes of seawater.

Parameters	Treatment 1 (100 L)	Treatment 2 (200 L)	Treatment 3 (300 L)	Treatment 4 (400 L)
Yield/platform (kg)	3.91 ± 0.32^{d}	7.53 ± 0.41^{c}	10.91 ± 0.52^{b}	14.86 ± 0.55^{a}
Days of solar drying	7.00 ± 1.00^{c}	11.00 ± 1.00^{b}	11.33 ± 1.52^{b}	19.00 ± 1.00^{a}
Production cycle per month	4	3	3	1
Production/month (kg)	15.67 ± 1.07^{c}	22.60 ± 0.90^{b}	32.75 ± 2.98^{a}	14.87 ± 1.45^{c}

Means in the same row with different letters are significantly different at $P < 0.05$

Solar sea salt production

Solar sea salt produced in high-density polyethylene platforms (HDPE) at different volumes of seawater is shown in Table 3. Produced salt ranged from 33.91±0.32 - 14.86±0.55 kg in each HDPE platform, depending on the volume of seawater used. Treatment 4 (400 liters seawater) significantly obtained the highest production with mean of 14.86±0.55 kg/HDPE platform followed by treatment 3 (300 liters seawater) with 10.91±0.52 kg/HDPE platform, treatment 2 (200 liters seawater) with 7.53±0.41 kg/HDPE platform, and treatment 1 (100 liters seawater) with lowest production of 3.91±0.32 kg/HDPE platform. Solar drying time to produce sea salt also depended on the volume of seawater in the HDPE platform. Treatment 1 statistically obtained the fastest solar drying time to produce salt in (7.00±1.00 days), while treatment 4 obtained a longer solar drying time of 19-20 days (19.00±1.00 days) (Table 3).

Relative to the drying time obtained from different treatments and if favorable conditions are sustained (bright and sunny days), treatment 1 could produce solar sea salt four (4) times/month while treatment 2 and 3 is three (3) times/month, and treatment 4 could produce only once in a month.

Based on the drying time and production cycle per month to produce sea salt at different treatments, statistical analysis showed that treatment 3 obtained the highest production of sea salt with a mean yield of 32.75±2.98 kg,/1 followed by treatment 2 with a mean yield of 22.60±0.90 kg/month. Treatments 1 (15.67±1.07 kg/month) and 4 (14.87±1.45) obtained the lowest sea salt production, and statistical analysis showed no significant difference between treatments.

In a similar study, Dr. Westly R. Rosario, former Center Chief of the Bureau of Fisheries and Aquatic Resources-National Integrated Fisheries Technology Development Center (BFAR-NIFTDC introduced the use of HDPE (food grade) plastic liner for the production of solar salt. Accordingly, the salt produced in HDPE plastic liners has good quality with high levels of minerals. His study showed that solar salt can be harvested every 6-7 days, in a 30 m² (2 m width x 15 m length) HDPE platform with 3 inches depth of seawater depending on the sun's heat and wind movement. Production of sea salt in the study of Dr. Rosario using HDPE liner is half cavan or 25 kg. The study of Dr. Rosario was limited only to production; thus, chemical, heavy metal, and microbial characterization of sea salt were not studied.

Another study by Aypa (1977) determined salt-making's viability in polyethylene plastic as a small-scale industry. Phase I of the study was conducted from January to February 1977, while Phase II was conducted from March to May of the same year. Each plastic compartment has a dimension of 2 ft × 3 ft × 4 inches which 25 liters of seawater was filled. The study showed that sea salt was produced in 7-8 days in polyethylene plastic without transferring water from one compartment to another. Chemical analysis of the product was not mentioned, but according to the report, the product is very white and acceptable to the public.

Chemical analysis of solar sea salt

Chemical analysis of produced sea salt at different treatments is presented in Table 4. Mean moisture content ranged from 7.65±0.13-7.68±0.15 %w/w, Sodium chloride from 81.93±0.87 - 82.57±0.20 %w/w, Acid insoluble from 157.00±10.44 - 164.00±3.46 mg/kg, Water insoluble from 0.11±0.02 - 0.12±0.03 %w/w, Calcium from 0.14±0.05 - 0.16±0.05 %w/w, Magnesium from 20.50±0.63 - 20.64±0.96 mg/kg, Iodine from 46.03±0.94 - 48.16±1.96 mg/kg and sulfate from 4.26±0.03 - 4.40±0.10 %w/w.

Table 4. Chemical analysis of solar sea salt produced in HDPE at different treatments.

Parameters	Treatment 1 (100 L)	Treatment 2 (200 L)	Treatment 3 (300 L)	Treatment 4 (400 L)
Moisture @ 110° C, %w/w	7.67±0.15	7.67±0.12	7.68±0.15	7.65±0.13
Sodium Chloride (NaCl), %w/w	81.93±0.87	82.49±0.17	82.50±0.15	82.57±0.20
Acid Insoluble, mg/kg	164.00±3.46	157.00±10.44	159.00±4.72	161.00±3.21
Water insoluble, %w/w	0.12±0.03	0.11±0.02	0.12±.0.2	0.12±0.03
Calcium (Ca), %w/w	0.14±0.05	0.14±0.05	0.15±0.01	0.16±0.05
Magnesium (Mg), mg/kg	20.57±0.74	20.57±0.92	20.50±0.63	20.64±0.96
Iodine (I), mg/kg	46.13±1.06	46.26±1.07	48.16±1.96	46.03±0.94
Sulfate (SO_4), %w/w	4.26±0.03	4.30±0.12	4.40±0.10	4.38±0.17

No significant difference in all parameters among treatments at P< 0.05

The Sodium chloride level (NaCl, %) obtained in this study at different treatments is lower than the other studies that also used the HDPE liner. In the study of Jumaeri *et al.* (2018), salt product innovation using HDPE geomembrane (P1-P6) has an average content of NaCl 95.75% with a range of NaCl content of 92.9%-98.87%. Therefore, the salt produced in their study fulfils the NaCl concentration by Indonesian Industrial Standards (SNI), which is at least 94.70%. Although no national and international standard for unrefined sea salt exists, the WHO, FAO, Codex Stan 150-1985 and ASIN law (Republic Act No. 8172) recommended and published the required chemical composition for food-grade salt or human consumption. According to WHO (1995), crude salt produced in a properly designed salt works has a purity of 90-95% NaCl, 1% calcium salts and 1-2% magnesium salts and 5-8% water. If the salt is washed and dried, its purity can be improved up to 99%.

In order to meet the nutritional needs of the Filipinos, the Republic Act No. 8172, otherwise known as the Act for Salt Iodization Nationwide (ASIN), was passed. The prescribed level of Iodine (I) in salt should be 45-74 mg/kg for every 1 kg if the salt came from the production site (local production) and port of entry (imported), while ≥ 25 mg/kg if salt came from the retail site (manufacturer). To ensure the stability of iodine, salt must conform to the following purity requirements such as moisture content of 4% for refined salt and 7% for unrefined salt, the minimum content of NaCl should not be less than 97% on a dry matter basis (which is also based on Codex Stan 150-1985 for food grade salt), maximum level of calcium and magnesium of 2%, the maximum level of water-insoluble of 0.2%, and heavy metal contaminants of 0.5 mg/kg of Arsenic (As) and Cadmium (Cd), 2.1 mg/kg of Lead (Pb) and 0.1 mg/kg of Mercury (Hg).

Solar sea salt produced in this study has an Iodine content of 46.03±0.94 - 48.16±1.96 mg/kg from different treatments, which conforms to the prescribed level of iodine in iodized salt, although the produced salt was not yet refined or subjected to cooking/refinement and iodization. This study only shows that iodine in sea salt could be obtained naturally by simply drying seawater through solar evaporation in the HDPE platform for a certain period.

Table 5. Heavy metal analysis of solar sea salt produced at different treatments.

Parameters	Treatment 1 (100 L)	Treatment 2 (200 L)	Treatment 3 (300 L)	Treatment 4 (400 L)	Codex maximum limit (µg/g)
Inorganic Arsenic (i-As), (µg/g)	0.075±0.76	0.075±0.75	0.075±0.99	0.076±1.91	0.5
Mercury (Hg), (µg/g)	Not detected	Not detected	Not detected	Not detected	0.05
Lead (Pb), (mg/kg)	9.07±0.71	9.41±0.48	9.24±0.22	9.27±0.60	1.0
Cadmium (Cd), (µg/g)	Not detected	Not detected	Not detected	Not detected	0.2

No significant difference in all parameters among treatments at $P< 0.05$

Heavy metal analysis of solar sea salt

Heavy metals detected in the produced solar sea salt are shown in Table 5. Of the four concerned heavy metals in sea salt, only two were detected. Results of the laboratory analysis revealed that Inorganic arsenic (i-As) and Lead (Pb) were present, while Mercury (Hg) and Cadmium (Cd) were not detected. The mean concentration of i-As in sea salt ranges from 0.075±0.75 - 0.076±1.91 µg/g, which passed the codex maximum limit of i-As (0.05 µg/g) for food-grade salt. On the other hand, the mean concentration of Pb ranged from 9.07±0.71-9.41±0.48 mg/kg, which exceeded the codex maximum limit of Pb (0.05 µg/g) for food-grade salt.

The high concentration of heavy metals detected in sediment in Paraoir may be due to a cement plant near the solar sea salt production. According to Ogunkunle and Fatoba (2014), cement industries, the most polluting industries in the world, are the main sources of heavy metals such as Cd, Cr, Pb, and Zn in the marine environment. Other possible sources are the boats used for fishing and recreation, which were observed in the two seawater collection sites that could contribute to the leaching of petroleum/gas.

In the study of Heshmati (2014), Pb content of refined and unrefined salt samples was 0.852 µg/g , and 1.22 µg/g, respectively, the first is below the permitted levels and the latter is higher. In another report in Iran, Pb concentration was 2.728 µg/g (range 0.01-5.8µg/g) (Cheraghali *et al.*, 2010) and in salt samples from Tehran, lead content was 0.87 µg/g (JahedKhaniki *et al.*, 2007) and 0.438 µg/g (Cheraghali *et al.*, 2010).

In a study done by Pourgheysari *et al.*, 2007) in Isfahan, lead content was determined to be 0.57 µg/g in refined salt and 0.61 µg/g in unrefined salt (Pourgheysari *et al.*, 2012). It was also was reported in the range of 0.5-1.64 µg/g in refined and unrefined table salt samples from Turkey, Egypt and Greece and 0.03 µg/g in Brazil (Soylak *et al.*, 2008).

Recently, the heavy metal contents of refined and unrefined table salts from Turkey, Egypt and Greece have been studied (Cheraghali *et al.*, 2010). According to the reported data, the concentration of Pb in table salt was between 0.54-1.64 µg/g. The Cd level in these samples was below 0.3 µg/g. Further, studies found a 200 times higher concentration of Pb in local cooking salt than other salts consumed in Nigeria. In a separate study, Cd levels of table salts used in Nigeria were reported as high as 4.5 µg/g (JahedKhaniki *et al.*, 2007). Concentrations of Pb and Cd in table salts consumed in Brazil were reported to be in the range of 0.03-0.1 µg/g and 0.01-0.03 µg/g, respectively (Pourgheysari *et al.*, 2012). Pb and Cd contents of table salts consumed in Iran seem more or less similar to the values reported from other countries. However, Cd, Pb, Hg, and As concentrations in table salts consumed in Iran are well below the maximum limits set by Codex.

World Health Organization's (WHO) recommendation of less than 2 g of sodium is per day (equivalent to approximately 5 g of salt per day) (WHO, 2007 and 2012).

Edible salt may contain contaminants in amounts and in such form that may harm the consumer's health. Some studies showed that heavy metals in different levels are found in edible salts (Cheraghali *et al.*, 2010; Eftekhari *et al.*, 2014; JahedKhaniki *et al.*, 2007, Pourgheysari *et al.*, 2012; Soylak *et al.*, 2008, Zarei *et al.*, 2011). Lead is one of the most toxic heavy metal that accumulates in the body, and data published in the literature indicates that its excessive intake harm different systems and organs, such as the central and peripheral neural system, gastrointestinal tract, muscles, kidneys, and hematopoietic system (Ciobanu *et al.*, 2021). The maximum permitted level of lead in food-grade salt is 2.0 µg/g according to the Codex legislation (Codex Alimentarius Commission, 2006) and from ASIN Law, which is one of the requirements of sea salt to be used for iodized salt.

Microbial analysis in solar sea salt

Table 6 shows the microbes detected from solar sea salt samples. The aerobic plate count was found highest in treatment 4 (3,500 CFU/g of the sample), followed by treatment 3 (3,200 CFU/g) of the sample, and the same plate counts were found in treatment 1 and 2 (3,100 CFU/g of the sample). Total coliform and *Staphylococcus aureus* in all treatments were found the same with a count of less than 10 CFU/g of sample. Based on the detection presumptive test, *Salmonella* sp. was found absent in all treatments. Escherichia coli in all treatments were found the same, with less than 3.0 grams per sample. The microbial community in the solar sea salt may be due to the exposure to open air during storage and handling. The absence of Salmonella is significant quality indicator of sea salt for human consumption.

Table 6. Microbial analysis in solar sea salt produced at different treatments.

Parameters	Treatment 1 (100 L)	Treatment 2 (200 L)	Treatment 3 (300 L)	Treatment 4 (400 L)
Aerobic Plate Count (CFU/g of sample) in agar plate, 35 °C, 48 hours incubation	3,100	3,100	3,200	3,500
Total Coliform Count (CFU/g of sample) in agar plate, 35 °C, 24 hours incubation	Less than 10	Less than 10	Less than 10	Less than 10
Staphylococcus aureus Count (CFU/g of sample) in agar plate, 35 °C, 48 hours incubation	Less than 10	Less than 10	Less than 10	Less than 10
Salmonella sp. Detection-Presumptive Test (per 25/g of sample)	Absent	Absent	Absent	Absent
Escherichia coli Count (Most probable number per gram of sample)	Less than 3.0	Less than 3.0	Less than 3.0	Less than 3.0

According to Maturin and Peeler (1998), aerobic plate count (APC) indicates the level of microorganisms in a product. The Philippines has no standard limits on microbiological standard for sea salt, though FAO recommended microbiological limits for various food products and most of the countries all over the world suggest conforming to the codex standard for food grade salt (Codex stan 150-1985). In terms of microbiological aspects, the absence of *Salmonella, Escherichia coli, Streptococcus faecalis* and coliforms is compulsory (Galvis-Sánchez *et al.,* 2013). The number of mesophile and halophile colonies should be less than 100 g^{-1}.

Enterobacteriaceae includes many bacteria found in the human or animal intestinal tract, including human pathogens such as *Salmonella* and *Shigella.* Enterobacteriaceae are useful indicators of hygiene and post-processing contamination of heat-processed foods. Their presence in high numbers (>104 per gram) in ready-to-eat foods indicates that an unacceptable level of contamination has occurred or there has been under-processing (e.g., inadequate cooking). Ready-to-eat foods should be free of Salmonella as consumption of food containing this pathogen may result in foodborne illness. The presence of this organism indicates poor food preparation and handling practices, such as inadequate cooking or cross-contamination. Consideration may also be given to investigating the health status of food handlers on the premises who may have been suffering from salmonellosis or asymptomatic carriers of the organism.

E. coli in sea salt is undesirable because it indicates poor hygienic conditions, leading to contamination or inadequate heat treatment. Ideally, *E. coli* should not be detected, and as such, a level of <3 per gram (the limit of the Most Probable Number test) has been given as the satisfactory criteria for this organism. The level of E. coli measured/detected at the different treatments in this study obtained satisfactory criteria for this organism. Levels exceeding 100 per gram of E. coli are unacceptable and indicate a level of contamination that may have introduced pathogens or that pathogens, if present in the food before processing, may have survived.

Contamination of sea salt with coagulase-positive staphylococci is largely a result of human contact. Contamination should be minimized through good food handling practices, and the organism's growth is prevented through adequate temperature controls. Unsatisfactory levels of coagulase-positive staphylococci indicate that time/temperature abuse of a food is likely to have occurred following improper handling during food preparation. A test for enterotoxin may be appropriate where levels of coagulase-positive staphylococci exceed 103 cfu per gram or where poor handling practices are suspected, but likely, viable organisms may no longer be present in significant numbers. The level of *Staphylocci* in this study was <10 cfu/g of sample and is therefore considered safe to consume. Levels of ≥104 cfu are considered potentially hazardous as foods with this level of contamination may result in food-borne illness if consumed.

Conclusion

The seawater used to produce solar sea salt, taken at a mean depth of 0.59±0.11 meters, had a salinity of 35-37 ppt, temperature of 29.1 - 31.54 ºC, and a pH of 8.21-8.03. Heavy metal concentrations in seawater were <0.008 mg/L, <0.001 mg/L, <0.005 mg/L, and <0.002 mg/L for i-As, Cd, Pb, and Hg, respectively.

Solar drying of seawater to produce salt took 7-8 days for 100 li, 11-12 days for 200 and 300 li, and 9-20 days for 400 li. Based on the drying time and production cycle per month, T3 produced the highest yield of 32.75±2.98 kg, followed by T2 with 22.60±0.90 kg. Treatments 1 and 4 produced the lowest yields of 15.67±1.07 kg and 14.87±1.45, respectively.

Results of chemical analysis on solar sea salt produced at different treatments showed no significant difference. The level of sodium chloride (NaCl) ranged from 81.93±0.87 - 82.57±0.20 %w/w, which is lower than the required NaCl content (not less than 97%) for food grade salt. On the other hand, laboratory analysis proved that solar sea salt produced has Iodine (I) content of 46.03±0.94 - 48.16±1.96 mg/kg, which is comparable to the iodized salt available in the market.

Heavy metals such as mercury (Hg) and Cadmium (Cd) in solar sea salt produced at different treatments were not detected. Inorganic arsenic (i-As) detected was in the range of 0.075±0.75- 76.81±1.91 µg/g, but passed the codex limit of 0.05 µg/g for food-grade salt. However, lead (Pb) content detected exceeded the codex limit of 2.0 µg/g for food-grade salt.

Microbial analysis, such as aerobic plate count, total coliform, *E. coli*, *Salmonella* sp., *Staphylococus aureus* in solar sea salt produced at different treatments passed the recommended microbiological limits for foods (spices, ingredients, and dried foods). The absence of Salmonella, as a major consideration in food safety, in produced solar sea salt showed that it is of good quality.

Recommendation

It is then, recommended that 300 liters of seawater is to be used as standard quantity in the HDPE platform with dimensions of 5m length, 1m width, and 0.25m depth since it significantly produced the highest yield per month with 3 cycles of production. The filtration system should be enhanced to reduce or eliminate the acid insoluble matter, heavy metal, and microbial contaminants.

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