Sea Salt Production Through Sun Drying Method in High-Density Polyethylene Platform

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ABSTRACT

Sea salt was produced by sun-drying seawater on high-density polyethylene (HDPE), and its quality was evaluated and compared to local and imported salt bought in the market based on chemical composition, microbial content, and heavy metal contamination. The study included three treatments: muslin cloth (T1), a 5 µm filter bag (T2), sand and gravel (T3), imported salt, and local salt. For T1-T3, drying took four days, with yields ranging from 8.52 - 8.64 kg. Moisture content ranged from 5.05 – 9.77 % w/w, sodium chloride content from 86.61 - 92.02 % w/w, and iodine levels from 0.93 – 30.24 mg/kg. No detectable levels of inorganic arsenic, lead, mercury, or cadmium were found in any samples. Sea salt produced using the 5 µm filter bag (T2) showed significantly improved quality compared to other treatments and outperformed traditional salt beds, cooked salt, and imported salt. Salts produced in HDPE met recommended iodine levels for household salt (30 - 70 mg/kg). Moreover, iodine levels in HDPE-produced salt were higher than those in local and imported salts. Microbial analysis, including for E. coli, showed satisfactory results across all samples. Overall, sun-drying seawater on HDPE, especially with a 5 µm filter, proved effective in producing high-quality, safe, and nutritionally adequate sea salt.

Keywords: Heavy metal, high-density polyethylene, iodine, microbial, sodium chloride

INTRODUCTION

Traditional salt production typically captures saltwater in shallow ponds where the sun evaporates most of the water. The concentrated brine precipitates the salt, which is then gathered by manual or mechanical harvesting machines. The methods of salt production in the Philippines were classified into four, namely, (1) solar evaporation method in ponds, (2) solar evaporation using PEP sheets, (3) cooking method, and (4) artisanal salt production [1]. Solar evaporation using PEP sheets is the most widely practiced method in the country because of low capital investment. With regards to volume, solar production in ponds dominates at 101,227 MT, or 88.31% of the total salt production. It was followed by cooking, solar salt production using PEP sheets, and artisanal salt production. Though there are different salt production methods in the Philippines, there is still a need to improve the yield and quality of the produced salt through innovation or other platforms. Repairing or upgrading existing salt farms is beset by challenges such as a shortage and increasing cost of essential materials, including clay tiles as flooring for salt beds and wood planks for the salt beds compartment. The scarcity of fuel for refining salt through cooking methods, such as biomass (rice husks, corn cobs, coconut husks) and wood, poses a significant challenge, particularly for small to medium-scale producers. The availability of biomass in the Philippines is now used in renewable energy facilities for the generation of electricity. Furthermore, the environmental impact of biomass burning, including carbon emissions, contributes to climate change and local environmental impacts. There are no standardized methods for salt production, such as a lack of standard design, process, and method for salt production, and reliance on age-old traditional salt-making practices that affect the productivity of salt farms in terms of yield and product quality [1].

High-density polyethylene (HDPE) liners have been commonly used in composite liners at the bottom of modern municipal solid waste landfills, water storage, and fish farms, and they have shown excellent performance in containing a broad range of chemicals [2, 3]. HDPE liners are available in various thicknesses and can be tailored to suit the specific requirements of different salt production facilities, ensuring optimal performance. There is increasing interest from salt farmers in the Philippines in using HDPE in the salt production industry due to its exceptional durability, resistance to chemical and environmental stress, and cost-effectiveness. Relative to the advantages of HDPE liners, this study was applied to produce salt with better purity than the traditional salt produced in salt beds or ponds. The study aims to produce sea salt through sun-drying in a high-density polyethylene platform and evaluate its quality. Further, salt farmers in the Philippines may consider using HDPE liners as an affordable and readily available alternative for salt bed crystallizers.

MATERIALS AND METHODS

Production Site and Set-up

The production of sea salt through solar evaporation was done in the coastal area of Paraoir, Balaoan, La Union. Nine (9) rectangular 250 µm High-density Polyethylene (HDPE) platforms were used in this study, which are collapsible (can be uninstalled if the rainy season comes). Each HDPE platform has dimensions of 5 m length, 1 m width, 0.25 m depth, and a thickness of 0.250 mm. Each HDPE platform was filled with 200 liters of seawater. The treatments were conducted in triplicate depending on the filtration system: Treatment 1 for muslin cloth, Treatment 2 for a 5 µm filter bag, and Treatment 3 for a sand and gravel filter (Figure 1). The HDPE platforms were installed and arranged in a Randomized Complete Block Design (RCBD).

Production Process

Sea salt was produced by collecting seawater directly from the sea using a 5 hp water pump and flexible hose into intermediate bulk containers (IBC) with a 1,000 L capacity. From the IBC tank, seawater passed into different filtration systems and was poured into the HDPE platform. Harvesting of sea salt was done once crystals of salt appeared in the HDPE platform. Salt harvesting in HDPE salt beds was based on visual evaluation, where crystals were considered mature when they appeared uniformly white, well-formed, and dry with a coarse, grainy texture. Maturity was also indicated by the clear separation of salt crystals from the HDPE surface and the absence of residual brine or wet spots. These visual signs reflected complete crystallization and minimal moisture content. Under favorable weather conditions, such maturity was typically achieved after four days of sun drying, making it the ideal time for harvesting. The collection of sea salt was done with an improvised bamboo rake. Collected sea salts were put in a bamboo woven basket to drain the liquid present and transported to the storage room for further evaluation and processing. Local and imported salt are bought in the market for the quality comparison and not included in the presentation of the production/ yield study.

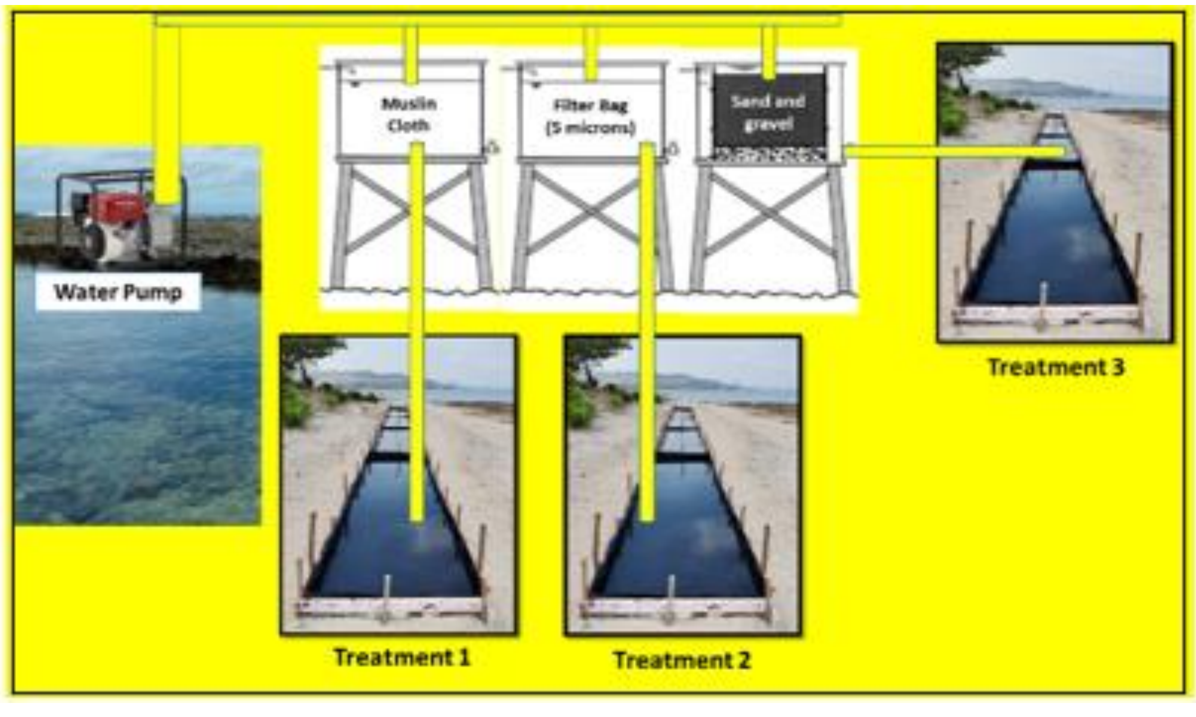

Figure 1. Production set up for sea salt in an HDPE platform

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Chemical, Heavy Metals and Microbial Analysis of Sea Salt

Sea salt samples from each treatment, including local salt from traditional methods and imported salt bought in the market, were weighed and brought to the Department of Science and Technology - Industrial Technology Development Institute (DOST-ITDI) for chemical, heavy metals, and microbial analysis. Tests for chemical analysis include sodium chloride, moisture, water-insoluble, magnesium, calcium, acid-insoluble, and iodine. Heavy metals include arsenic, cadmium, lead, and mercury. Tests for microbial analysis include aerobic plate count, total coliform, Escherichia coli, Salmonella sp., and Staphylococcus aureus.

Salt samples were analyzed using standard laboratory methods. For chemical analysis, moisture content was determined by oven drying at 105°C until a constant weight was reached, sodium chloride was measured via Mohr's titration using silver nitrate, and iodine content was assessed through iodometric titration with sodium thiosulfate. Heavy metal analysis involved acid digestion of samples followed by detection of arsenic, lead, cadmium, and mercury using Atomic Absorption Spectrophotometry (AAS). Microbial analysis was performed by dissolving salt samples in sterile distilled water, followed by serial dilution and culturing on selective media to detect E. coli and other potential contaminants, with incubation at 35–37°C for 24–48 hours.

Statistical Analysis

All the collected data were subjected to statistical analysis with one-way ANOVA, and any difference between the treatment means was analyzed using LSD in SPSS version 23.

RESULTS

Sea salt produced in high-density polyethylene platforms with different filtration systems is shown in Table 1. Sea salt production ranges from 8.52 ± 0.43 - 8.64 ± 0.35 kg. Treatment 2 (5 µm filter bag) obtained the highest yield with a mean of 8.64 ± 0.35 kg, followed by treatment 1 (muslin cloth) with 8.64 ± 0.35 kg and treatment 3 (sand and gravel) with the lowest yield of 8.52 ± 0.43 kg. Though treatment 2 obtained the highest yield, statistical analysis showed no significant difference from other treatments. Sun drying of sea salt is completed in four (4) days with seven (7) monthly production cycles. Relative to the drying time obtained from different treatments, and if favorable conditions are sustained (bright and sunny days), all treatments could produce 34 kg of salt for every HDPE platform monthly.

Table 1. Production of sea salt in HDPE platform

Parameter	Treatment 1 (muslin cloth)	Treatment 2 (5 microns)	Treatment 3 (sand and ravel)
Yield (kg)	8.61 ± 0.27	8.64 ± 0.35	8.52 ± 0.43
Days of solar drying	4.00 ± 1.19	4.00 ± 1.20	4.00 ± 1.42
Production cycle every month	7	7	7
Monthly production (kg)	34.44 ± 1.07	34.56 ± 0.90	34.08 ± 2.98

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

Chemical analysis of the produced sea salt at different treatments and its comparison to local and imported salt samples bought in the market are presented in Table 2. Sea salt produced at different treatments has a mean moisture content ranging from 5.05 – 9.77 % w/w, sodium chloride from 86.61 - 92.02 % w/w, acid insoluble from 71.83 – 157.53 mg/kg, calcium from 0.15 – 0.45 % w/w, magnesium from 0.11 – 0.82 mg/kg and iodine from 0.93 – 30.24 mg/kg. Water insoluble was not detected in all treatments. Acid insoluble was significantly higher in treatment 1 (132 mg/kg) than in treatments 2 and 3, with mean values of 76.58 and 76.41 mg/kg, respectively. The analysis showed that acid insoluble in sea salt produced in all treatments is significantly lower in locally produced salt in traditional salt beds but significantly higher than imported salt. Water insoluble in sea salt produced in all treatments and salt available in the market was not detected.

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Table 2. Chemical analysis of sea salt produced at different treatments

Parameter	Treatment 1 (muslin cloth)	Treatment 2 (5 microns)	Treatment 3 (sand and gravel)	Imported Salt	Local Salt
Moisture @ 110° C, % w/w	7.72 ± 0.02^{b}	5.05 ± 0.03^{e}	6.50 ± 0.02^{c}	6.37 ± 0.03^{d}	9.77 ± 0.04^{a}
Sodium Chloride (NaCl), % w/w	88.90 ± 0.02^{d}	91.72 ± 0.02^{b}	91.4 ± 0.10^{c}	92.02 ± 0.03^{a}	86.61 ± 0.03^{e}
Acid Insoluble, mg/kg	132.00 ± 1.00^{b}	76.58 ± 0.10^{c}	76.41 ± 0.03^{c}	71.83 ± 0.15^{d}	157.33 ± 1.15^{a}
Water insoluble, % w/w	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected
Calcium (Ca), % w/w	0.34 ± 0.05^{b}	0.45 ± 0.01^{a}	0.35 ± 0.01^{b}	0.25 ± 0.05^{c}	0.15 ± 0.01^{d}
Magnesium (Mg), % w/w	0.34 ± 0.11^{c}	0.82 ± 0.01^{a}	0.58 ± 0.02^{b}	0.11 ± 0.01^{e}	0.18 ± 0.02^{d}
Iodine (I), mg/kg	30.14 ± 0.18^{a}	30.09 ± 0.01^{a}	30.24 ± 0.17^{a}	1.24 ± 0.03^{b}	0.93 ± 0.03^{c}

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

Table 3 shows the microbial composition obtained from the analysis of sea salt samples. The aerobic plate count was highest in local salt with 3.5 x 10^3 cfu/g, followed by treatment 3 with 3.2 x 10^3 cfu/g, and was found lowest in treatments 1, 2, and imported salt with 3.1 x 10^3 cfu/g. The total coliform and Staphylococcus aureus in all treatments were the same, with a count of less than 10 cfu/g of the sample in an agar plate, 35 °C, 24 h incubation. Salmonella sp. was absent in all treatments based on the presumptive test detection in an agar plate, 35 °C, 48 h incubation. Escherichia coli in all treatments was the same, with less than 3.0 cfu/g of sample.

Based on the analysis, heavy metals such as inorganic arsenic, lead, mercury, and cadmium were not detected in any of the samples. Evaluating the traces of heavy metals in sea salt for human and animal consumption is crucial in complying with the ASIN Law (RA 8172) and ensuring consumers' safety.

Table 3. Microbial analyses in solar sea salt produced at different treatments

Parameter	Treatment 1	Treatment 2	Treatment 3	Imported Salt	Local Salt	ASIN Law (mg/kg)
Aerobic plate count (x10^3 cfu/g)	3.1	3.1	3.2	3.1	3.5	<10
Total coliform count (cfu/g of sample)	<10	<10	<10	<10	<10	<10
Staphylococcus aureus count (cfu/g of sample)	<10	<10	<10	<10	<10	<10
Salmonella sp. detection – presumptive test (per 25/g of sample)	Absent	Absent	Absent	Absent	Absent	Absent
Escherichia coli count (per g of sample)	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0

DISCUSSION

Tabafunda and Tadeo [4] studied using HDPE with 250 µm thickness in sea salt production using solar evaporation. Their study aims to determine the yield and drying rate of salt produced in HDPE at different volumes of seawater. Based on the result of the study, the produced salt ranged from 33.91 ± 0.32 to 14.86 ± 0.55 kg in each HDPE platform, depending on the volume of seawater used. Treatment 4 (400 L seawater) significantly obtained the highest production with a mean of 14.86 ± 0.55 kg/HDPE platform followed by treatment 3 (300 L seawater) with 10.91 ± 0.52 kg/HDPE platform, treatment 2 (200 L seawater) with 7.53 ± 0.41 kg/HDPE platform, and treatment 1 (100 L seawater) with the 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 (7.00 ± 1.00 days), while treatment 4 obtained a longer solar drying time of 19 - 20 days (19.00 ± 1.00 days).

Moisture content in this study was significantly highest in treatment 1 and lowest in treatment 2. The highest moisture content was found in local salt produced in traditional methods. The highest sodium chloride content in this study was found in imported salt bought in the market, and the lowest was in locally produced salt. On the use of HDPE and filtration methods, sodium chloride in treatment 2 was significantly higher than in treatments 1 and 3. Although there is no national and international standard for unrefined sea salt, 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 for human consumption. The raw salt may contain natural secondary products, which are present in varying amounts depending on the origin and method of production of the salt, and which are composed mainly of calcium, potassium, magnesium, and sodium sulfates, carbonates, bromides, and calcium, potassium, magnesium chlorides as well. Natural contaminants may also be present in amounts varying with the origin and the salt production method. In the study of Jumaeri et al. [5], salt product innovation using HDPE geomembrane has an average content of NaCl of 95.75 % w/w with a range of NaCl content of 92.9 % - 98.87 % w/w. According to WHO (1995), crude salt produced in a properly designed salt works has a purity of 90 – 95 % NaCl, 1 % calcium salts, 1 – 2 % w/w magnesium salts, and 5 - 8 % w/w water, and if the salt is washed and dried its purity can be improved up to 99 %. The Republic Act No. 8172, otherwise known as the Act for Salt Iodization Nationwide (ASIN), suggested that to ensure the stability of iodine, salt to be iodized must conform with the following purity requirements such as moisture content of 4 % w/w for refined salt and 7 % w/w for the unrefined salt, the minimum content of NaCl should not be less than 97 % w/w on a dry matter basis (which is also based on Codex Stan 150 - 1985 for food grade salt), the maximum level of calcium and magnesium of 2 % w/w, maximum level of water-insoluble of 0.2 % w/w, and heavy metal contaminants of 0.5 $mg.kg^{-1}$ of Arsenic (As) and Cadmium (Cd), 2.1 mg/kg of Lead (Pb) and 0.1 mg/kg of Mercury (Hg).

Results of analysis showed that the iodine content detected in salt produced in HDPE, regardless of the filtration system, complied with the standard under the Republic Act No. 8172 or the Act for Salt Iodization Nationwide law in 1995, which is 30-70 mg/kg. On the other hand, local salt produced in traditional salt beds and imported salt did not comply with the standards set in RA 8172. The Philippine government responded to this program and promulgated the Republic Act No. 8172, or the Act for Salt Iodization Nationwide law in 1995, requiring that all food-grade salt be fortified with iodine. Iodine is commonly added as potassium iodate (KIO_3) due to its chemical stability in the presence of contaminants, moisture, and oxygen in the air. This study only shows that iodine in sea salt could be obtained naturally by sun-drying seawater in the HDPE platform for a certain period. The World Health Organization’s (WHO) recommendation is to consume less than 2 g of sodium daily [6].

Edible salt may contain contaminants in amounts and in such forms that may harm the consumer’s health. Some studies showed that heavy metals at different levels are found in edible salts [7, 8, 9, 10, 11]. Lead is one of the most toxic heavy metals that accumulate in the body, and data published in the literature indicate that its excessive intake harms different systems and organs, such as the central and peripheral neural system, gastrointestinal tract, muscles, kidneys, and hematopoietic system [12]. The maximum permitted level of lead in food-grade salt is 2.0 $\mu g.g^{-1}$ according to the Codex legislation [13] and from ASIN Law, which is one of the requirements of sea salt to be used for iodized salt. Recently, the heavy metal contents of refined and unrefined table salts from Turkey, Egypt, and Greece have been studied [7]. 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. [14]. Further studies found a 200 times higher concentration of Pb in local cooking salt than in other salts consumed in Nigeria. In a separate study, Cd levels of table salts used in Nigeria were reported to be as high as 4.5 µg/g [9]. 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 [10]. 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.

The microbial community obtained in the study may be due to the exposure of solar sea salt in the open-air during storage and handling. The absence of Salmonella is a significant quality indicator of sea salt for human consumption. Aerobic plate count (APC) indicates the level of microorganisms in a product (Bower et al., 2018) The Philippines has no standard limits on microbiological standards for sea salt, though FAO recommends microbiological limits for various food products, and most countries all over the world suggest conforming to the Codex standard for food-grade salt 150-1985. The number of mesophile and halophile colonies should be less than 100 g^{-1}. Enterobacteriaceae includes many human or animal intestinal tract bacteria, 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 ($>10^4$ cfu/g) in ready-to-eat foods indicates that an unacceptable level of contamination has occurred or there has been under-processing. Ready-to-eat foods like salt 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. Ideally, E. coli should not be detected, and as such, a level of < 3 cfu/g (the limit of the most probable number test) has been given as the satisfactory criteria for this organism. In this study, the level of E. coli measured at the different treatments, including imported and local salt bought in the market, met the satisfactory criteria for this organism. Levels exceeding 100 cfu/g 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 should be prevented through adequate temperature controls. Unsatisfactory levels of coagulase-positive staphylococci indicate that time and 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/g or where poor handling practices are suspected, but likely, viable organisms may no longer be present in significant numbers. The level of Staphylococci in this study has <10 cfu/g of sample and is therefore considered safe to consume. Levels of $\geq 10^4$ cfu/g are considered potentially hazardous as foods with this level of contamination may result in foodborne illness if consumed [15].

CONCLUSION

Using filter bags (5 microns and sand and gravel) significantly improved the quality of sea salt in HDPE through the solar evaporation method. Sea salt produced in HDPE, regardless of filtration methods, had better quality (chemical properties) than locally produced salt and imported salt. Chemical analysis proved that sea salt produced in HDPE through sun drying obtained a level of natural Iodine (I) that is within the recommended level of Iodine in salt (30-70 mg/kg) at the household level. Further, the iodine content obtained in all treatments is higher than locally produced salt and imported salt. Salt produced in treatments 2 and 3 is recommended for human and animal consumption and other applications for food and processing industries.

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Conflict of Interest

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