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High-Productivity Traditional Bali *Palung* Salt Method for Small Production Fields

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Abstract: Used for many generations in several Bali villages, *palung* is a traditional salt production method involving filtration through a soil–sand medium. This study examines and compares the chemical composition, yield, and crystal structure of salt produced using the *palung* method at three different locations in Bali. The filtration of seawater through the soil–sand medium produced NaCl with a purity of 81.7–90.7%, a higher purity than that produced in Indonesia using conventional methods. The observed productivity of the salt *palung* field was very high compared to that of conventional and other unconventional/modern methods (100–135 ton/ha). Atomic absorption spectrometry revealed that salt samples from the three different sites contained no heavy metals. The observed dendritic structure of *palung* salt crystals differs from conventional salt, which is more amorphous. Since the *palung* method requires less land area for production, smaller salt farms can use this method.

Keywords: *palung* salt production, Bali, soil-sand filtration, characterization, purity.

适用于小型生产领域的高生产力传统巴厘岛槽

摘要: 在巴厘岛的几个村庄中使用了好几代，槽是一种传统的盐生产方法，涉及通过土壤沙介质进行过滤。本研究检查并比较了在巴厘岛三个不同地点使用槽方法生产的盐的化学成分、产量和晶体结构。海水通过土壤-沙介质过滤产生的氯化钠纯度为81.7-90.7%，比印度尼西亚使用传统方法生产的纯度更高。与传统和其他非常规/现代方法（100-135吨/公顷）相比，盐巴隆田的观察到的生产力非常高。原子吸收光谱法显示来自三个不同地点的盐样品不含重金属。观察到的槽盐晶体的树枝状结构与常规盐不同，后者更无定形。由于槽方法需要较少的生产土地面积，较小的盐场可以使用这种方法。

关键词: 槽盐生产，巴厘岛，土砂过滤，表征，纯度。

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1. Introduction

Increasing the quantity and quality of salt production is the focus of several recent studies [1], [2], [3], [4], [5]. A simple recrystallization method was reported to increase the NaCl content to over 99%. Another study investigated using a prism greenhouse method combined with several salt production technologies, including a geomembrane and threaded filter technology [2], reporting a 3-fold increase in productivity and an increase in NaCl content from 85% to 95%. Salt production in the prism greenhouse was described as beneficial regarding faster production time and resistance to harsh weather. Artemia, a genus of aquatic crustaceans also known as brine shrimp, has been used to remove unwanted salts such as Ca and Mg in the production of edible salt [6]. Seawater reservoir flows have been modified to accelerate evaporation to collect concentrated seawater in a shorter time. Evaporation pan size has been investigated, showing that small pans provide greater solar radiation exposure (112%) than do large pans (136%) and increase the efficiency of land use by as much as 28% in area and 75% in volume [7].

Almost all salt ponds in Indonesia apply a four-table seawater evaporation method and are operated during the dry season, from July through September [8]. The majority of these seasonal salt production fields are in the northern part of Java and Madura, the center for salt production in Indonesia. The productivity is as high as 200 ton/ha in the long dry season (5–6 months) [8], [9].

In addition to the modern technological approaches, methods based on traditional wisdom merit investigation. One traditional technology is *palung*, a method used on the island of Bali [10]. This technology comes from Tejakula Village, Buleleng Regency, Bali Province. *Palung* technology is used in several other areas, including Amed village (Karangasem) and Kusamba village (Klungkung district) [11]. As Bali is a famous tourist destination, this excellent quality salt has penetrated the global market. Nevertheless, little is known about the technical aspects of this *palung* method.

Palung technology relies on concentrated brine manufacturing processes that employ a Tulud filtration system, the local name for sand overlay, a tool called "Tinjung," and a drying process. The primary feature of the *palung* method is filtration using a mixture of sand and soil found in Tulud and Tinjung. This filter is produced by water with a high NaCl content. None of the studies have investigated the filtration performance of this mixture of soil and sand, based on our observation which becomes the scientific novelty of this research. The study examines and compares the chemical composition, yield, and crystal structure of salt produced using the *palung* method at three different locations in Bali. Therefore, it is essential to ensure the necessary parameters to achieve industrial salt high-quality grade production, considering that the traditional practice has survived in generations in Bali in a unique way. The characterization is merely focused on *the palung* method, where field production is conducted in Bali. This study will also reveal how relatively narrow land can produce quality salt.

2. Materials & Methods

Seawater and sand were collected from 3 villages in Bali: Les Village, Tejakula, Buleleng Regency (Sample 1); Culik Village, Amed, Karangasem Regency (Sample 2); and Kusamba Village, Dawan, Klungkung Regency (Sample 3) (Fig. 1).

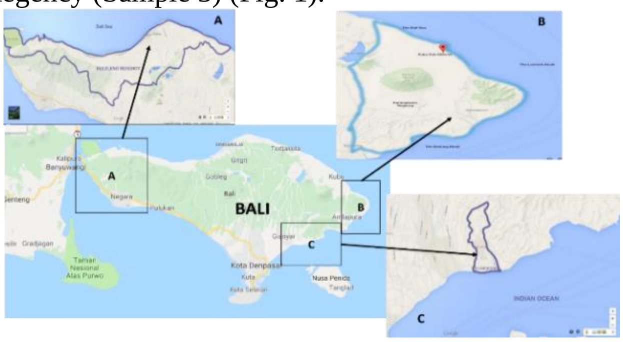


Fig. 1 Map indicating the locations of the three sample collection sites on the island of Bali: Les Village, Tejakula Sub-district, Buleleng Regency (Sample 1); Culik Village, Amed Sub-district, Karangasem Regency (Sample 2); and Kusamba Village, Dawan Sub-district, Klungkung Regency (Sample 3)

2.1. Filtration Assay

Chemicals for argentometry analysis included $AgNO_3$ (p.a. 99.9%, Merck, Indonesia) for extraction and hydrodistillation and K_2CrO_4 (Emsure, 99.5%, Merck, Indonesia) used as an indicator. On the other hand, a given mass of sand (m_{p1}) was packed into a filtration chamber to prepare the filter. Seawater (volume, V_{W1}) was added to the filtration column. The time required for the water to flow through the sand filtration bed was recorded (t_W). The seawater flow rate (Q_W, mL/minute.g) was calculated using Equation 1.

$$Q_w = \frac{V_{w1}}{t_{w1} x m_{p1}} \quad (1)$$

2.2. Characterization and Analysis

The NaCl concentration was determined using the Argentometry titration method (SNI 01-3556-2010), and the concentrations of lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr^{6+}) were carried out using atomic absorption spectrometry (SNI 6989.8, SNI 6989.16, SNI 6989.71, and SNI 19-6964.2). Ion Chromatography was used to determine the ionic composition of the salt. The anion content assayed included F, Cl, Br, NO_3, PO_4, and SO_4. In contrast, the cation content assayed included Li, Na, Mg, Ba, Ca, and K. Ion content analyses used the absolute calibration curve method with CM and UV Detectors. Scanning electron microscopy (SEM) (SEM-EDX JEOL JSM-6510LA) was used to analyze the structure of salt crystals under 150× and 5000× magnification.

2.3. Salt Production System Layout

The *palung* salt production system consists of four parts: *Tulud*, *Tinjung*, *Brombong*, and *palung* (Fig. 2A). The details of these four parts are very different from the conventional Maduranese four-table system, which is a ubiquitous method of salt production in Indonesia [8]. The area of the *palung* system, about half a hectare in one integrated area, is far less than in the conventional system, as shown in Fig. 2B. In some places, the production area is much smaller and contained. Seawater is carried in a handmade container made from palm leaves (Fig. 2B).

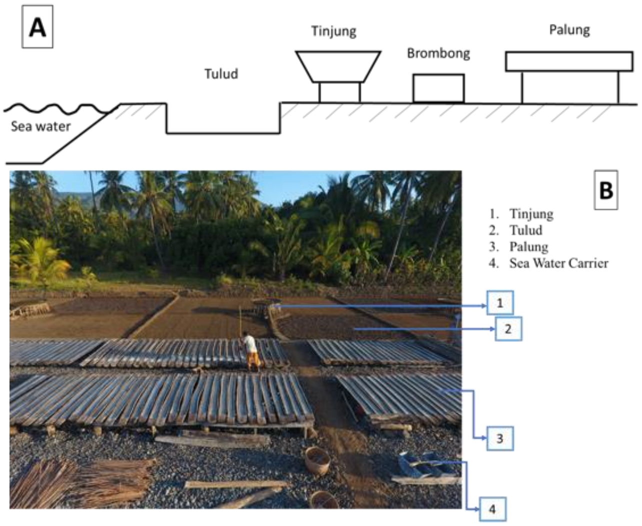


Fig. 2 Salt production system in Tejakula sub-district, Bali: (A) schematic diagram of the system; (B) system field view

The seawater is poured into the *Tulud*, a small field prepared with a sand–soil mixture on top (Fig. 3). Seawater is usually poured into the tulud several times, and the amount of water poured is not precisely measured. The *Tulud* is allowed to dry after each pouring, resulting in a salt-rich top layer.

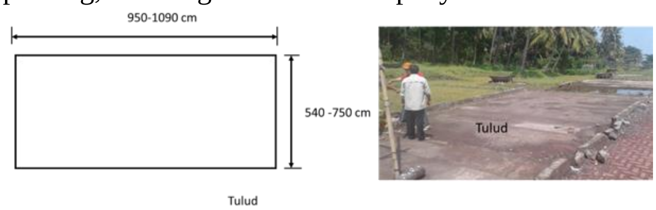


Fig. 3 The tulud – a small field prepared with sand–soil mixture on top

The salt-rich sand–soil medium is then moved into the *Tinjung* (Fig. 4), a large bowl. Seawater is poured over the sand–soil medium inside the *Tinjung*, and the salt concentration of the seawater (Baume) increases as it filters through the salt-rich medium. The water is allowed to drip into the *Brombong* (a water reservoir) (Fig. 5).

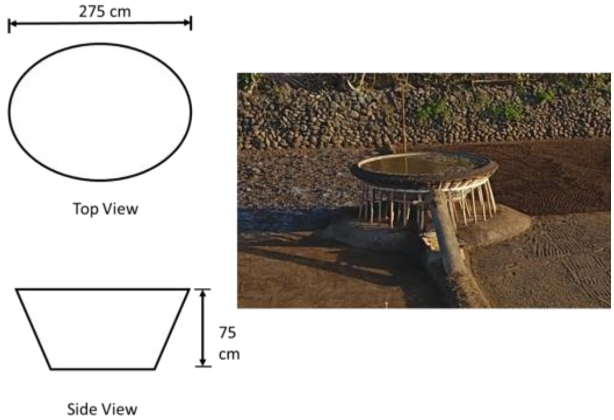


Fig. 4 The *Tinjung* – a large bowl containing the filtration media. Top and side view drawings with dimensions (left); photograph of a *Tinjung* (right)

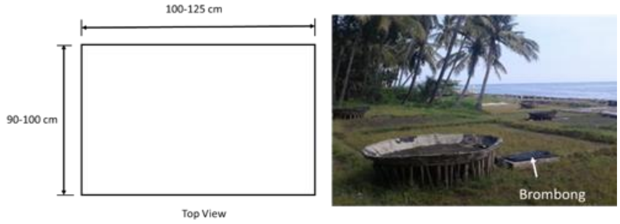


Fig. 5 The *Brombong*. Top view drawing with dimensions (left); photograph of a *Brombong* beside a *Tinjung* (right)

The concentrated brine is then dried in a *palung* for 2–3 days, depending on the weather, after which the salt can be harvested. The *palung* is a long, fringed board made from the coconut tree trunk and is used for evaporating the concentrated seawater (Fig. 6). The method of *palung* salt production in the Tejakula sub-district serves as a model for other regions of Bali.

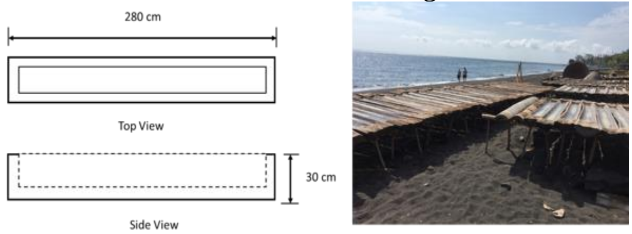


Fig. 6 The *palung*, a long, fringed board made from the coconut tree trunk, is used for evaporating the concentrated seawater. Top and side view drawings with dimensions (left); photograph of a *palung* on the beach (right)

3. Results & Discussion

3.1. Seawater Filtration

The NaCl concentration of the seawater was assayed using the Argentometry method (Table 1). Because seawater processing aims to increase the NaCl concentration in the product, NaCl was the only seawater component measured in our samples.

Table 1 NaCl concentration of seawater samples from several salt production regions in Indonesia

Seawater source	NaCl	Reference

	(mg/L)	
Les Village, Tejakula	23.7	This study
Culik Village, Amed	31.9	This study
Kusamba Village, Dawan	31.3	This study
Gisik Cemandi Village, Sidoarjo	39.6	Calculated based on Apriani *et al*. [12]
Kalanganyar Village, Sumenep	37.6	Calculated based on Apriani *et al*. [12]
Tlanakan Village, Pamekasan	33.0	Calculated based on Apriani *et al*. [12]
Pesanggrahan Village, Bangkalan	17.8	Calculated based on Apriani *et al*. [12]
Tambak Langgon Village, Surabaya	54.8	Calculated based on Apriani *et al*. [12]
Brengkok Village, Lamongan	50.2	Calculated based on Apriani *et al*. [12]

The NaCl concentration of the seawater taken from Les villages was 23.7 mg/L, which is slightly lower than that of seawater samples taken from Culik (31.9 mg/L) and Kusamba villages (31.3 mg/L). All of these NaCl concentrations are typical of seawater in other salt production regions in Indonesia.

Therefore, the relationship between the volume of seawater passing through the sand filtration column (V_{w1}) and the flow time in the column (t_{w1}) in sand from Les, Culik, and Kusamba villages was investigated. The volume of seawater passing through the sand filtration column with time (t_{w1}) follows a half parabolic curve (V_{w1}) (Fig. 7). This trend is similar in all 3 seawater samples, with relatively high values of R^2 in Les, Culik, and Kusamba villages (0.9902, 0.998, and 0.997, respectively). The results show that larger volumes of seawater take longer to pass through the sand filtration column. The more extended period of filtration is caused by water retention in the sand in the filtration column. Because each sample site has a different type of sand, the filtration coefficients differ between the 3 samples, contributing to the differing curves.

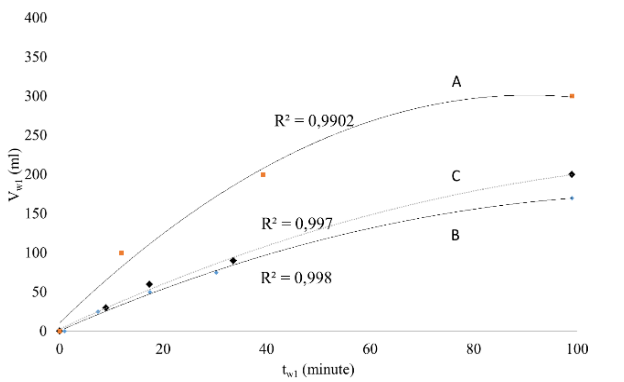


Fig. 7 Relationship between the volume of seawater passing through the sand filtration column (V_{w1}) and the flow time in the column (t_{w1}) using sand from Les (A), Culik (B), and Kusamba (C) villages

The relationship between seawater flow rate per unit of sand mass (Q_w) and the volume of seawater passing through the sand filtration column (V_{w1}) in Les, Culik, and Kusamba villages is shown in Fig. 8. The curves are typical of sand filtration, where an increased volume of seawater passing through the sand column results in an exponential decrease in the flow rate per unit sand mass.

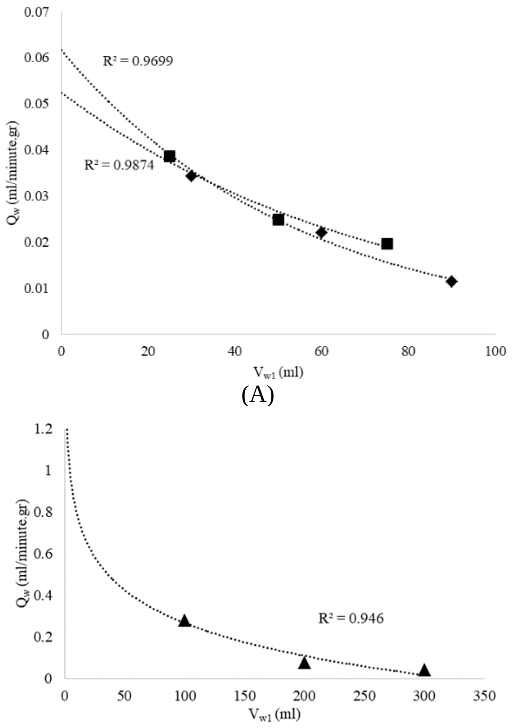


Fig. 8 Relationship between seawater flow rate per unit of sand mass (Q_w) and seawater volume passing through the filtration column (V_{w1}) during seawater filtration with sand from (A) Les village; and (B) Culik and Kusamba villages

The seawater filtered faster through the soil from Les village than that from the other villages. The filter medium in Les village is much sandier than that of the other villages. In the Culic and Kusamba village, the soil is easily seen in the medium, although beach sand still predominates.

3.2. NaCl Content of Salt Products

NaCl and heavy metals in salt products from Les, Culik, and Kusamba villages were measured using Argentometry. The Les village product had the highest NaCl concentration (90.51–90.70%), followed by the products from Culik and Kusamba villages (86.40–88.74% and 81.71-85.46%, respectively) (Table 2).

Table 2 NaCl content of salt product according to the production method (*Recalculated from original data; N/A: Not Available)

Method	NaCl (%)	Productivity (ton/year.ha)	Ref.
Prism Greenhouse	95	100	[2]
Tunnel Greenhouse	91.0–93.0	77–80	[3]
Geomembrane	89.7–95.7	88–170*	[1, 5]

Ceramic media	79.7–91.3	48–93*	[1, 5]
Palung Salts:			
(A) Les Village	90.51–90.7	100–135	This Research
(B) Culik Village	86.40–88.74	100–135	This Research
(A) Kusamba Village	81.71–85.46	100–135	This Research
Traditional/Conventional	80.0–85.0	60	[4]
Brine water extensive evaporation	80–85.0	N/A	[5]

The NaCl content of the salt product from Les village is higher than that from the other two villages, even though NaCl concentration in the Les village seawater is lower (Table 1). This difference in the NaCl content of the final product may result from more effective filtration in Les village (Figures 8). The NaCl content of the traditional *palung* salt (81–90.7%) is lower than that produced by more modern methods such as the Prism greenhouse (95%) and Tunnel greenhouse (91.0–93.0%). However, the NaCl content of *palung* salt is much higher than that of brine water extensive evaporation and other conventional methods (80–85%).

The three villages produce 100–135 tons per hectare per year. This productivity is much higher than that of the other methods, except the geomembrane method. Although the NaCl concentration of the *palung* salt is somewhat lower than that of the modern systems, the productivity of *palung* salts is much higher. Another benefit of the *palung* method is its suitability for areas that do not have large sandy beaches. The land in most areas of Bali and other tourism territories is expensive and in short supply.

Heavy metal concentrations in salt products Atomic Absorption Spectrophotometry showed no lead, cadmium, mercury, or hexavalent chromium were present in the salt products from all three areas in Bali (Table 3) are thus safe for consumption. No heavy industries are in the vicinity of these villages.

Table 3 Heavy metals concentration in salt products from three Bali villages (* as determined by atomic absorption spectrophotometry)

Salt source	Concentration (ppm)*			
	Pb	Cd	Hg	Cr^{6+}
(A) Les village, Tejakula	<0.005	<0.005	<0005	<0.005
(B) Culik village, Amed	<0.005	<0.005	<0.005	<0.005
(C) Kusamba village, Dawan	<0.005	<0.005	<0.005	<0.005

In terms of concentrations of cations and anions in salt products, they were analyzed by IC assay (Tables 4 and 5). Sodium and chloride were the predominant cation and anion, respectively, in the salt products. The highest sodium and chloride concentrations were found in the product from Culik Village, at 98.44% and 97.32%, respectively. These results are as expected that, given that the predominant salt component is NaCl. Another cation found in salt products is barium, which was very low in the *palung* salt product from Kusamba Village (0.22%) but higher in that from Les Village (7.47%) and Cirebon West Java (13.01%). Another anion found in salt products is sulfate, which was low in all samples. Barium in salt products is expected to be in the form of barium sulfate. Thus, while barium itself is moderately toxic to humans, barium sulfate is nontoxic because it is insoluble.

Table 4 Cation content of the salt product as determined by chromatography

Retention Time (min)	Cation	Les Village %	Culik Village %	Kusamba Village %	Cirebon West Java Salt %
1.607	Li	0.00	0.00	0.00	0.00
1.880	Na	92.53	98.44	97.52	86.99
2.826	Mg	0.00	0.00	2.27	0.00
3.039	Ba	7.47	1.56	0.22	13.01
3.323	Ca	0.00	0.00	0.00	0.00
3.950	K	0.00	0.00	0.00	0.00
	Sum	100.00	100.00	100.00	100.00

Table 5 Anion content of the salt product as determined by chromatography

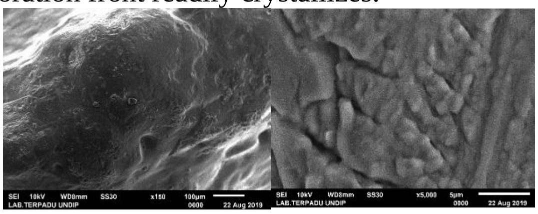
Retention Time (min)	Anion	Les Village %	Culik Village %	Kusamba Village %	Cirebon West Java Salt %
1.425	F	0.00	0.00	0.00	0.00
1.879	Cl	96.51	97.32	96.83	98.59
2.484	Br	0.00	0.00	2.27	0.00

2.635	NO3	0.00	1.56	0.22	0.00
2.859	PO4	0.00	0.00	0.00	0.00
3.337	SO4	3.49	2.68	3.17	1.41
	Sum	100.00	100.00	100.00	100.00

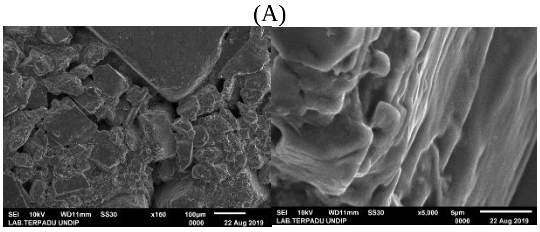
3.3. Crystal Structure of the Salt Products

A significant difference was observed between the crystalline structure produced by the conventional method, which uses evaporation alone (Fig. 9A), and the *palung* method (Fig. 9B–D). The salt structure produced by the conventional method is amorphous, which can result from humidity, and consists of nanoscale cubes of crystal. In contrast, the *palung* salt crystals consist of nanoscale dendrites. This dendrite structure results from the supersaturation of the solution, which inhibits crystallization [13]. This inhibition of NaCl crystallization allows impurities such as calcium and potassium salts to crystallize and precipitate out of the solution earlier, resulting in a final product with higher purity.

Two major factors account for the difference in NaCl crystal morphology when crystallization occurs in porous sand: (i) supersaturation is increased by the higher evaporation rate of the solution in porous sand (as compared to open pond evaporation) due to its larger specific surface area; and (ii) the highly supersaturated solution is sustained longer in a porous medium (pores size, radius < 1 μm) before crystallization starts due to the Laplace effect of the curvature of the solution in a capillary or a pore [14]. Once the solution reaches a larger pore or a stone surface, the Laplace effect of curvature no longer applies, and the highly supersaturated solution at the evaporation front readily crystallizes.



(A)



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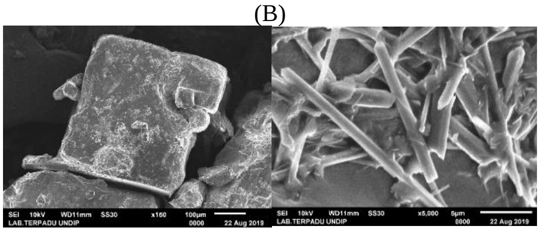

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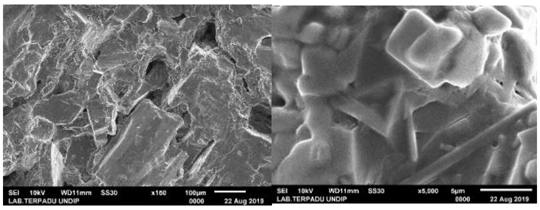

(D)

Fig. 9 SEM analysis of salt crystals from A) Conventional method; B) Les Village; C) Culik village; D) Kusamba village (150× and 5000× magnification)

4. Conclusion

The filtration process of seawater with soil-sand medium produces a salt quality of around 81 to 90.7%, similar to other conventional methods in Indonesia. Analysis of salt *palung* products in several locations does not indicate the presence of heavy metal contamination. The crystal structure of *palung* salt differs from that produced by the conventional method. The high NaCl content and higher yield of *palung* render this method very suitable for farmers with a small land area (minimum required, 0.5–1 hectare). The result significantly promises to address salt production with high-quality grades by adapting the Palung method as an applicable salt production reference standard. On the other hand, it also helps boost farmers' welfare indirectly by delivering alternative ways to produce salt as a commodity in limited area's production.

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