BIO Web of Conferences **146**, 01002 (2024) https://doi.org/10.1051/bioconf/202414601002
BTMIC 2024

The utilization of salt particles from seaweed processing by-products for low-sodium salt production

Nizar Amir[1], *Makhfud* Efendy[2*], *Wiwit Sri Werdi* Pratiwi[2], *Fiki Milatul* Wahyu[1], *Mochamad Yusuf* Efendy[1], *Misri* Gozan[3], *Caroline* Chan[4]

[1]Department of Mechanical Engineering, Universitas Trunojoyo Madura, Bangkalan, 69162, Indonesia
[2]Department of Marine Science, University of Trunojoyo Madura, Bangkalan 69162, Indonesia
[3]Department of Chemical Engineering, Universitas Indonesia, Kampus Baru U.I., Depok 16424, Indonesia
[4]Newcastle Business School, University of Newcastle, Sydney, Australia

Abstract. Utilizing mechanical rotary and sieve separators to collect salt particles from the surface of dried *Eucheuma cottonii* represents an innovative methodological approach. In this study, a mechanical rotary separator was employed to separate impurities like salt particles, mud, stones, and seaweed chunks from the surface of the dried *Eucheuma cottonii*. Following that, a multi-layer vibro sieve separator was employed to separate the salt particles from impurities. This study aimed to investigate the influence of the separation duration in both equipment for separating impurities on the surface of the dried *Eucheuma cottonii*, and collecting salt particles from the impurities. Mass balance is utilized to calculate, quantify, and analyze the distribution of impurities mass throughout the entire process line. Impurities produced during the process were characterized using a binocular stereo microscope (Olympus SZ30). The sodium content in the salt particle produced was analyzed using the titration method. The study showed that using a mechanical rotary separator for about 3 minutes on 500 grams of dried *Eucheuma cottonii* generated 7.6 grams of impurities. Using the multi-layer vibro sieve separator, only 3.8 grams of the initial 7.6 grams of impurities were identified as uncontaminated salt particles. As a result, these salt particles contain a minimum of 60% sodium chloride, presenting a viable alternative to table salt as a low-sodium source. This research demonstrates a significant contribution through its effective methodology for extracting salt particles from dried *Eucheuma cottonii*, indicating its potential as a viable source of low-sodium salt.

1 Introduction

Numerous studies have demonstrated that excessive consumption of high-sodium salt by humans is considered one of the main factors contributing to the development of high blood pressure or hypertension [1–4]. Notably, Indonesia has the highest prevalence of hypertension among all countries, and this number continues to rise each year [5, 6]. Hypertension is closely linked to cardiovascular complications, and high sodium intake plays a crucial role in the onset of these diseases [7, 8]. This can be explained by the fact that high sodium salt readily attracts water [9]. Excessive consumption of high-sodium salt leads to water retention, which subsequently results in an increase in blood volume, ultimately leading to elevated blood pressure [10–12]. The application of low-sodium salt can serve as a potential solution to reduce high blood pressure, lower the risk of cardiovascular disease, and promote a healthier lifestyle [13, 14]. Numerous researchers have been exploring various methods to produce low-sodium salt. In a study [15], low-sodium salt was produced by adding multiple times brine water during the salt production process, specifically when the salt flowers began to form. This production was conducted on a laboratory scale at the salt house plant of Universitas Trunojoyo Madura.

The research findings indicated the success of this method in producing low-sodium salt, with sodium content as low as 61%. An alternative process, as proposed by [16], involves the production of low-sodium salt. This approach employs the re-crystallization method on a laboratory scale. Sodium chloride (NaCl) and potassium chloride (KCl) are blended in various mass ratios before being dissolved in water. Once entirely dissolved, both substances are heated in a glass beaker to initiate salt crystal formation. The resulting salt crystals are then dried using an oven set at 80°C. The study unveiled that the most practical combination of NaCl and KCl is at a 1:1 mass ratio, heated at 70°C, resulting in salt with a sodium content of 60%. Both previous studies utilized wet methods in producing low-sodium salt, resulting in higher costs due to the significant energy requirements. Therefore, a more cost-effective approach is required as a solution. In literature [17], researchers employed a simple dry mixing method involving NaCl and KCl in a stirred reactor. The study aimed to explore the effects of particle size and weight ratios in the production of low-

* Corresponding author: nizar.amir@trunojoyo.ac.id

sodium salt. To analyze the ion concentration of Na+ and K+ in salt particles, Atomic Absorption Spectrometry (AAS) and X-ray fluorescence were used. The findings revealed that the most favorable conditions for producing low-sodium salt, with NaCl content at 54.40% and KCl content at 40.33%, were achieved using 40 mesh particle size and a mass ratio of 1:3. There is a need for a cost-effective production method to simplify processes and reduce the overall cost of the final product [18–20]. Additionally, the innovative utilization of industry by-product materials presents an opportunity to transform them into profitable products [21]. In the seaweed processing industry, there are two type of seaweed which has a high economic value, such as *Eucheuma cottonii* and *Gracilaria sp* [22]. In this industry, *Eucheuma cottonii* is processed to produce carrageenan, while *Gracilaria sp*. is used for agar production [23, 24].

Fig. 1. The salt on the surface of dried *Eucheuma cottonii*.

Eucheuma cottonii is cultivated in seawater and subsequently dried by local farmers near the beach employing tray nets or bamboo trays. Once dried, it is packaged and delivered to the industry. Before it is prepared for processing using various methods in industry, *Eucheuma cottonii* seaweed must undergo a cleaning process to remove surface impurities. These impurities typically include salt particles, mud, stone, and other contaminant, and this study aims to investigate their presence further. Figures 1 and 2 illustrate the dried *Eucheuma cottonii* seaweed, displaying its surface impurities and a corresponding microscopic image. In these figures, the presence of a white coloration indicates the presence of crystal salt adhering to the surface of the *Eucheuma cottonii* seaweed.

Fig. 2. Microscope image of salt adhering to the surface of dried *Eucheuma cottonii.*

Indonesia ranks as one of the largest producers of fresh *Eucheuma cottonii*, with an annual production exceeding 9.78 million tons [25]. Nevertheless, during the drying process, out of the 9.78 million tons of fresh *Eucheuma cottonii*, only approximately 1 million tons of dried *Eucheuma cottonii* are produced, containing 35-40% moisture content. Given its abundance, this by-product resource is a promising candidate for utilizing the salt particles found on the seaweed's surface during the cleaning process. However, various mechanical processes are essential to separate salt particles from the surface of the seaweed, as presented in Figure 3. This figure showcases the mechanical rotary separator utilized within the industry to eliminate impurities from dried *Eucheuma cottonii* seaweed. This equipment operates based on the centrifugal force mechanism. It involves spinning dried *Eucheuma cottonii* at medium speed, effectively separating impurities adhering to the seaweed surface. These impurities are directed to the lower compartment while the cleaned, dried *Eucheuma cottonii* remains within the equipment. Workers then retrieve the cleaned seaweed for further processing in subsequent steps after multiple equipment operations. Subsequently, additional procedures are conducted to segregate the salt particles from other impurities, such as mud, stone, and debris.

Fig. 3. The rotary separator used in the industry for the removal of impurities from dried *Eucheuma cottonii.*

Drawn back from the literature review, humans' excessive intake of high-sodium salt is regarded as one of the primary factors contributing to health issues. Therefore, numerous researchers have been motivated to develop low-sodium salt using various methods to create a healthier salt suitable for human consumption. However, there has been a noticeable gap in experimental research regarding producing salt particles from the by-products of the seaweed processing industry as a source of low-sodium salt. Additionally, there is a need to minimize both cost and complexity by employing a simpler process and equipment. For instance, utilizing mechanical rotary and vibro sieve separators could offer a more streamlined approach. Consequently, the detailed analysis of the salt particle content on the surface of *Eucheuma cottonii* seaweed has remained unexplored, as has its conversion capacity. This study aims to address these gaps, introducing a novel approach to this field. This study contributes to outlining the production process for generating salt particles from a by-product of the seaweed industry, which is a source of low-sodium salt.

2 Material and methods

2.1 Materials

The dried *Eucheuma cottonii* with an initial water content of 38% on a wet basis was used in this study. The dried *Eucheuma cottonii* was provided by P.T. Kappa Carrageenan Nusantara and, during the work assisted by their worker. The dried *Eucheuma cottonii* was collected through a random sampling process to ensure the data's representativeness and mitigate bias, hereby enhancing the validity and reliability of the research findings.

2.2 Experimental production process

2.2.1 Sample preparation

The procedures employed in this experiment are based on practices within the seaweed processing industry but conducted on a laboratory scale. Before commencing the experiment, all equipment was cleaned with distilled water and then dried in an oven to ensure the absence of any additional contamination. The experiment began with randomly selecting 15 samples, each weighing 500 grams, of dried *Eucheuma cottonii*, which were subsequently inserted into the mechanical separator equipment.

2.2.2 Mechanical separation

The mechanical separator equipment separated the dried *Eucheuma cottonii* from their impurities. This study employed a compact mechanical separator mirroring industrial equipment, measuring 0.3 meters in diameter and 1 meter in length. The dried *Eucheuma cottonii* underwent sieving using this mechanical separator for durations ranging from 1 to 3 minutes, operated at 72 revolutions per minute (RPM). The impurities were collected in the bottom of the equipment using a stainless steel container, while the clean, dried *Eucheuma cottonii* were transferred to the output compartment and collected in another stainless container. Throughout the separation process, the duration was varied from 1 to 3 minutes to investigate the optimal separation duration. The impurities produced during the separation process in the mechanical separator equipment were weighed to determine the quantity of impurities derived from the initial 500 grams of dried *Eucheuma cottonii*. After completing the initial separation process, the impurities were transferred to the sieving process.

2.2.3 Sieving process

The sieving process was conducted with the objective of further categorizing the impurities into specific groups. The equipment functions by segregating materials according to particle size, employing multiple layers of screens arranged in a stacked configuration. Each successive layer features smaller opening sizes. This experiment uses a multi-layer vibro sieve separator and comprises six different filter sizes: 2 mm, 1 mm, 0.63 mm, 0.5 mm, 0.25 mm, and 0.125 mm. The use of these various filter sizes ensured thorough filtration of all impurities. The duration of the sieving process was also varied, ranging from 0.5 to 2.5 minutes. Once the sieving process was completed, each category of impurities was collected and transferred to separate glass containers for subsequent analysis. All measurements were conducted a minimum of three times, and Microsoft Excel software was employed to calculate the average values. All graphical data presented in the results were derived from these average values obtained during the experimental data analysis.

2.2.4 Quality control

All laboratory equipment underwent multiple rinses with distilled water and was subsequently dried at 40°C before utilization in this experiment. Throughout the laboratory analysis, operators adhered to wearing lab coats and nitrile gloves to prevent the introduction of additional impurities. Following each experiment, the mechanical and vibro sieve separators were rinsed with distilled water and dried using a clean rubber rag to mitigate the possibility of additional impurities.

2.3 Identification of samples

The sample's identification is determined through a mass balance, followed by its characterization using a microscope and titration methods using SNI 3556:2016 [26]. This analysis involves treating every chloride ion within the sodium chloride (NaCl) sample with silver ions (Ag^+) obtained from an $AgNO_3$ solution. This procedure is carried out with the assistance of a potassium chromate solution (K_2CrO_4). A mass balance offers a systematic and quantitative method for monitoring and quantifying mass distribution within a system, process, or operation [27, 28]. The information derived from the mass balance results plays a crucial role in ensuring efficient and sustainable operations, minimizing adverse environmental impacts, and maintaining product quality control across various industries and applications [29–31]. The mass balance information is obtained from the source material. Then, it is updated after the material goes through the mechanical separator equipment and further refined during the sieve separation process. This information provides a detailed account of the mass generated at each process stage. Moreover, the impurities' characteristic distribution was identified using a binocular stereo microscope (Olympus SZ30) to examine specific components like salt particles, stones, mud, and other impurities.

3 Result and discussion

Figure 4 provides a detailed breakdown of the mass balance for impurities production while processing 500 grams of dried *Eucheuma cottonii*. The processing involves both mechanical separator equipment and a multi-layer vibro sieve separator. Using the mechanical separator equipment, 500 grams of dried *Eucheuma cottonii* can generate a maximum of 7.6 grams of impurities.

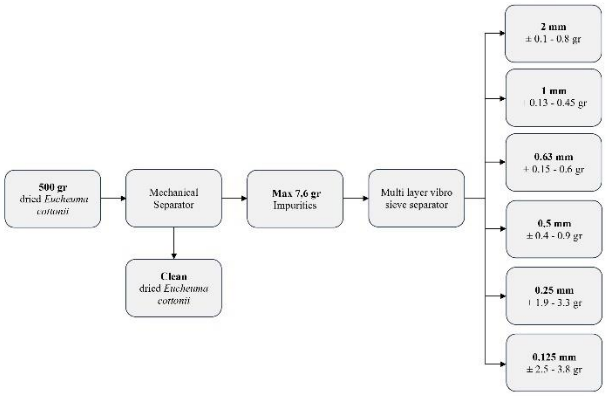

Fig. 4. Mass balance resulting from the processing of 500 grams of dried *Eucheuma cottonii*.

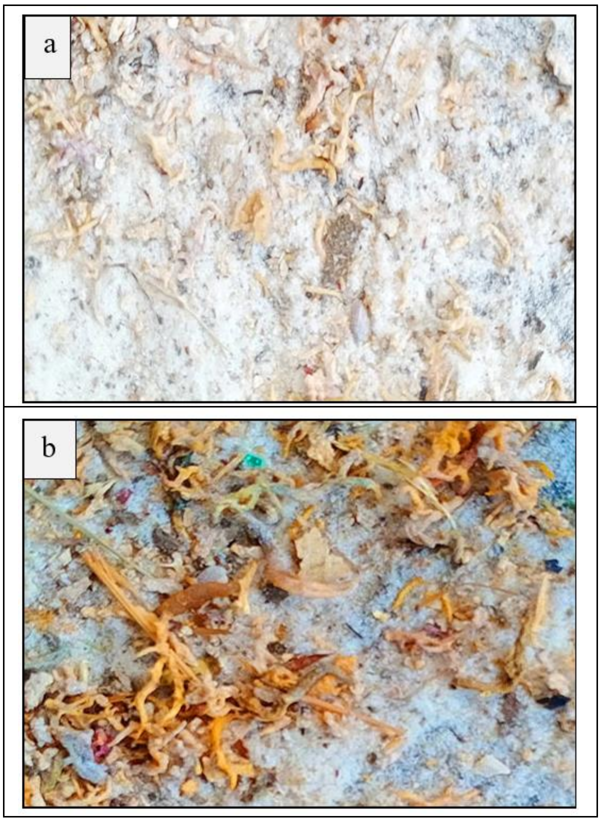

Fig. 5. The material produced from the mechanical separator consists of: (a) salt particles and mud, and (b) stones, seaweed chunks, and shells.

As indicated by the microscope identification, the impurities collected from the mechanical separation equipment comprise salt particles, stones, mud shells, and chunks of seaweed, as illustrated in Figure 5. Based on these results, it is evident that the mechanical separator equipment is effective in cleaning and separating impurities like salt particles, mud, stones, and shells from the surface of dried *Eucheuma cottonii*. The separation duration also plays a vital role in the separation process [32–34]. Figure 6 illustrates the relationship between the duration of separation and the production of impurities, along with the corresponding production percentages during the separation process in the mechanical separator equipment. This observation indicates that a longer separation duration leads to increased impurities production. The separation duration increased from 1 to 3 minutes, the impurities production increased from 4.19 grams to 7.6 grams. In summary, to effectively clean the dried *Eucheuma cottonii*, a minimum of 3 minutes in the separation process is required, resulting in a higher production of impurities.

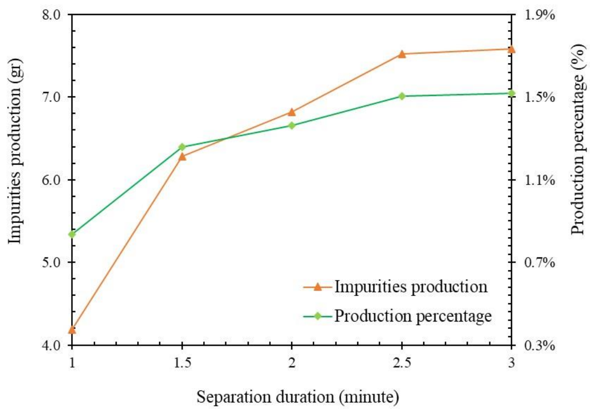

Fig. 6. The variation in impurities production and its corresponding production percentage with an increase in separation duration.

In this case, 500 grams of dried *Eucheuma cottonii* can generate 7.6 grams of impurities, which include salt particles, stones, mud shells, and chunks of seaweed. Figure 6 also offers insight into the impurities content on the surface of dried *Eucheuma cottonii*, which accounts for 1.52% of the total weight. This figure can serve as a reference for the potential utilization of these impurities from dried *Eucheuma cottonii* in the production of salt particles. Nonetheless, further processing of the impurities is necessary by utilizing a multi-layer vibro sieve separator to collect salt particles specifically. During the sieving process, impurities are divided across six sieve layers based on their respective sieve sizes. The detailed results of the sieving process are provided in Figures 7a and 7b. According to the sieving process, the impurities are categorized into six specific groups. These categories include Seaweed chunks (2 mm), Stone and shell (1 mm), Smallest chunks (0.63 mm), Mud, Finest chunks (0.5 mm), Coarse salt particles (0.25 mm), and Salt Particles (0.125 mm).

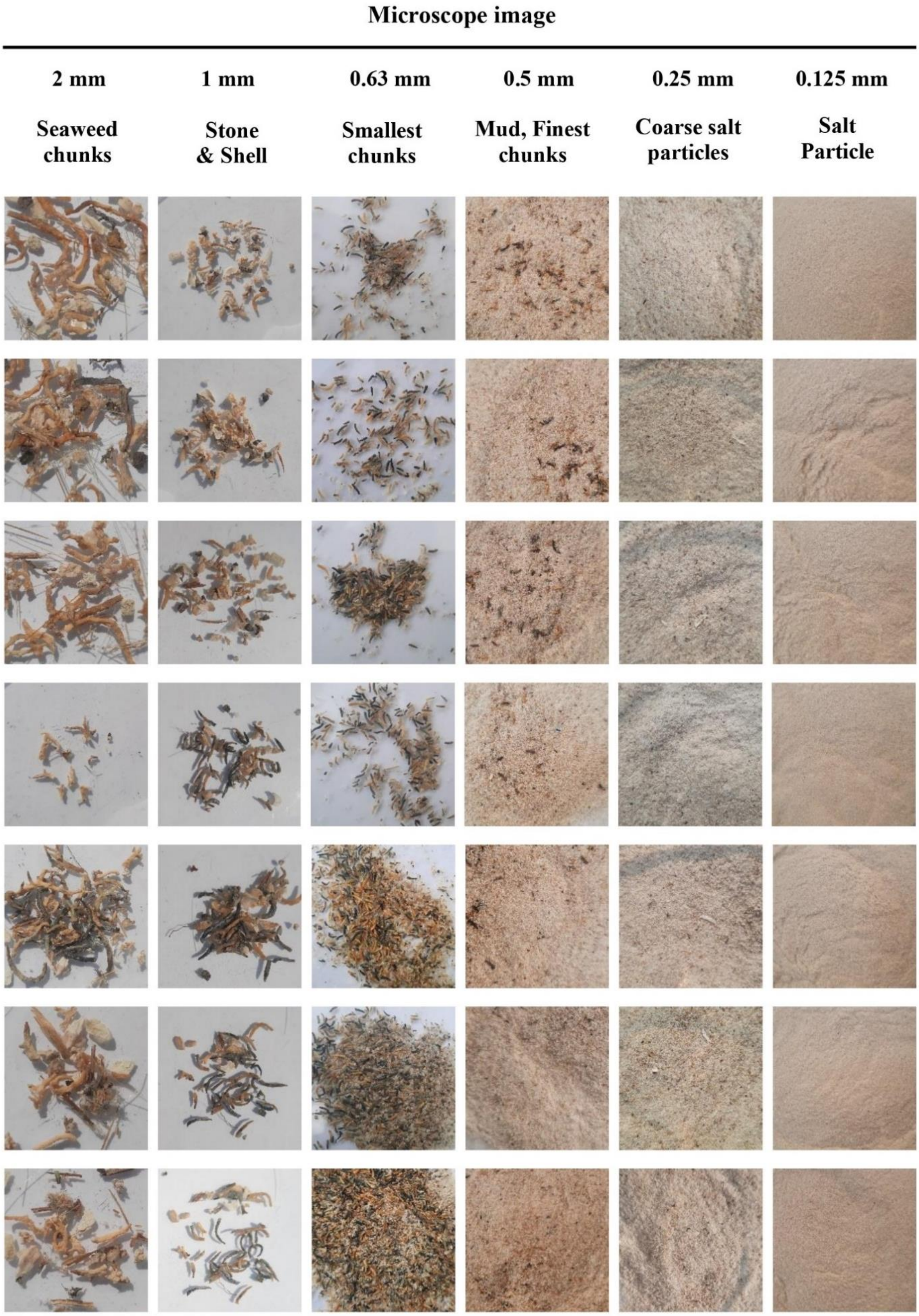

Fig. 7a. Images of various types of impurities observed under a microscope at different sieve sizes (continued).

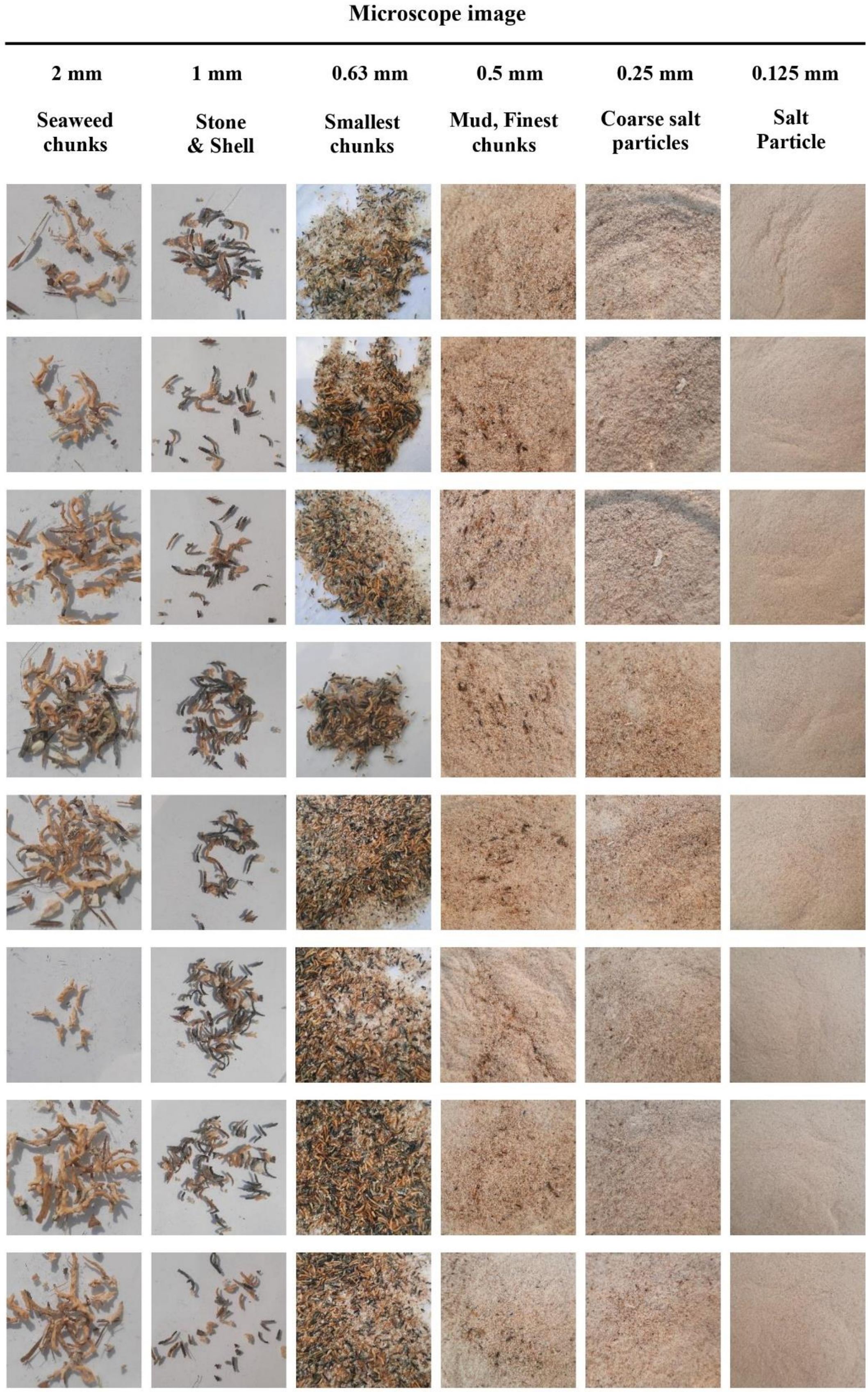

Fig. 7b. Images of various types of impurities observed under a microscope at different sieve sizes (continued).

Figures 7a and 7b reveal that using a 0.125 mesh size sieve effectively produces clean salt particles separated from stones, mud, and seaweed chunks. Figure 8 depicts the relationship between the duration of sieving and the production of impurities within their specific groups, including stone and shell, smallest chunks, mud, finest chunks, coarse salt particles, and salt particles. It is evident that an increase in the sieving duration optimizes the division of impurities into their respective groups. For instance, in the case of salt particles, when the sieving duration is extended from 0.5 minutes to 2.5 minutes, salt particle production increases from 2.5 grams to 3.8 grams. Moreover, salt particles contribute significantly to the overall weight of the impurities, accounting for approximately 50 percent of the total weight, as illustrated in Figure 8.

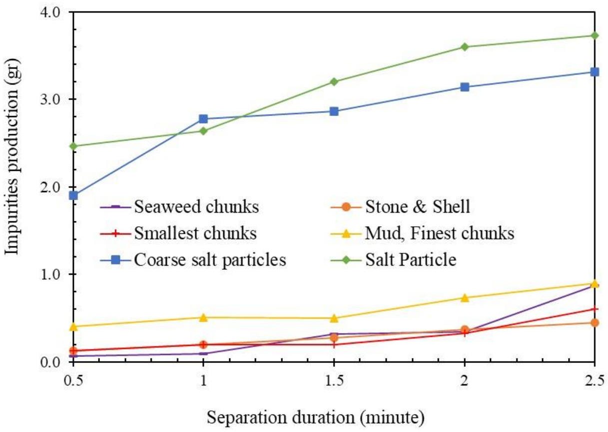

Fig. 8. The variation in impurities production, particularly within their respective groups with an increase in separation duration.

Out of the approximately 7.6 grams of impurities, 3.8 grams constitute salt particles. This can be explained by the fact that *Eucheuma cottonii*, when cultivated in seawater, retains seawater on its surface during harvesting [35, 36]. Subsequently, as the wet *Eucheuma cottonii* undergoes open sun drying, the seawater on its surface evaporates and crystallizes, transforming into salt particles. This phenomenon can be attributed to the presence of salt particles on the surface of dried *Eucheuma cottonii*. Moreover, impurities like stones, shells, mud, and seaweed chunks constitute a relatively small portion of the impurities found in dried *Eucheuma cottonii*. Additionally, the presence of mud can be attributed to the conditions of the coastal area where the seaweed is cultivated.

A cleaner coastal environment, with less mud, leads to cleaner seaweed, thereby reducing the proportion of mud in the impurities [37–40]. In order to guarantee that the salt particles produced from the processing of dried *Eucheuma cottonii* have low sodium content, a titration method was employed. This experiment revealed that the salt particles contain sodium with a range of 68% to 83%, and close to the national standards for low-sodium salt consumption [41]. Nevertheless, for further research, it is crucial to investigate in a more detailed analysis of the salt content, including other mineral components, such as potassium or calcium, as well as the presence of potential metal contaminants like lead, cadmium, mercury, and arsenic, as written in the standards for low-sodium salt. The results obtained from the titration method showed that the salt particles contain 68% to 83% sodium, making them suitable as a source for producing low-sodium salt with an additional fortification process. The fortification process has the potential to decrease sodium content while simultaneously enhancing the nutritional value of the salt consumed by humans. The herb fortification can be incorporated to enhance the multivitamin content in the low-sodium salt during the production process [42]. This fortification does not increase the sodium content but it enriches the salt with supplemental multivitamins and minerals, all remaining compliant with the established standards. In preparing the low-sodium salt derived from salt particles, further processing steps are necessary, including washing, dissolution in ultra-pure water, and re-crystallization, to ensure that the low-sodium salt derived from salt particles produced as a by-product of the seaweed processing industry meets the standards for dietary salt in Indonesia and is safe for human consumption. The salt wash process aims to eliminate soluble and insoluble impurities from salt particles by rinsing them with saturated brine. The use of saturated brine serves to sustain the weight of the salt particles during the washing process. Typically, this procedure involves multiple washing stages to ensure the complete removal of all impurities. In the re-crystallization process, the salt needs to dissolve in water. To ensure the absence of additional impurities during this dissolving stage, ultra-pure water is specifically chosen for use. The re-crystallization stage involves evaporating the water from the salt solution, a process that demands high energy consumption. Typically, this requires the use of multiple evaporation stage equipment.

The production of salt particles from the seaweed processing industry by-product is feasible. To estimate the potential of the output of salt particles from dried *Eucheuma cottonii,* the total production of dried *Eucheuma cottonii* in Indonesia is considered. Annually, Indonesia produces one million tons of dried *Eucheuma cottonii.* Processing one million tons of dried *Eucheuma cottonii* using the method proposed in this study can generate 7,600 tons of salt particles, serving as a source of low-sodium salt.

4 Conclusion

A novel approach to producing salt particles from by-products of the seaweed processing industry has been successfully developed and evaluated. Starting with 500 grams of dried *Eucheuma cottonii*, the separation process in the mechanical separator equipment produced 7.6 grams of impurities. Subsequently, during the sieving process in the multi-layer vibro sieve separator, these impurities were transformed into 3.8 grams of salt particles, which have been verified to contain a sodium content with a range of 68% to 83%. This innovative method has the potential to generate approximately 7,600 tons annually in Indonesia, serving as a source of low-sodium salt. However, it is important to note that this study represents a preliminary investigation.

Further detailed analysis of the salt content is required, including other mineral components such as potassium or calcium. Additionally, it is essential to investigate the potential presence of metal contaminants like lead, cadmium, mercury, and arsenic, following the standards for low-sodium salt. These parameters could serve as the basis for future research in this field.

The authors would like to acknowledge the support provided by the University of Trunojoyo Madura. The authors are also thankful for the facilities and technical support from Kappa Carrageenan Nusantara Co., Ltd.

References

1. N. S. A. Aziz, R. Ambak, F. Othman, F.J. He, , M. Yusof, F. Paiwai, S. A. Ghaffar, M.F. Mohd Yusof, S. M. Cheong, G. MacGregor, T. Aris, *Risk factors related with high sodium intake among Malaysian adults: findings from the Malaysian Community Salt Survey (MyCoSS) 2017–2018*, J. Heal. Popul. Nutr. **40**, 1 (2021)
2. I. Drenjacnevic-Peric, B. Jelaković, J. H. Lombard, M. P. Kunert, A. Kibel, M. Gros, *High-salt diet and hypertension: Focus on the renin-angiotensin system*, Kidney Blood Press. Res. **34**, 1 (2011)
3. A. Mente, M. O'donnell, S. Yusuf, *Sodium intake and health: What should we recommend based on the current evidence?*, Nutrients. **13**, 3 (2021)
4. A. Mente *et al.*, *Association of Urinary Sodium and Potassium Excretion with Blood Pressure*. N. Engl. J. Med. **371**, 601 (2014)
5. Y. Turana, J. Tengkawan, A. A. Soenarta, Asian management of hypertension: Current status, home blood pressure, and specific concerns in Indonesia, J. Clin. Hypertens, **22**, 483 (2020)
6. E. Muchtar, E. Sanjaya, F. I. Hariadi, *Human machine interface on e-Shrimp as smart control system for whiteleg shrimp pond*, 2017 Int. Symp. Electron. Smart Devices, ISESD 2017, 24 (2017)
7. K. T. Mills, A. Stefanescu, J. He, *The global epidemiology of hypertension*, Nat. Rev. Nephrol., **16**, 223 (2020)
8. . D. Fuchs, P. K. Whelton, *High Blood Pressure and Cardiovascular Disease*, Hypertension, **75**, 285 (2020)
9. N. Amir, M. Efendy, D. A. S. Rini, M. Gozan, *Effect of Washing Operating Parameters on the Quality of Dried Salt in Salt Washing Plant*, J. Biosyst. Eng, (2022)
10. R. Agócs, D. Sugár, A. J. Szabó, I*s too much salt harmful ? Yes Blood pressure Dietary Approaches to Stop Hypertension Trial of Hypertension Prevention*. Pediatr, Nephrrology, **35**, 1777 (2020)
11. P. Nijst, F. H. Verbrugge, L. Grieten, M. Dupont, P. Steels, W. H. W. Tang, W. Mullens, *The pathophysiological role of interstitial sodium in heart failure*, J. Am. Coll. Cardiol. **65**, 378 (2015)
12. Q. Wu, G. Burley, L. C. Li, S. Lin, Y. C. Shi, *The role of dietary salt in metabolism and energy balance: Insights beyond cardiovascular disease*. Diabetes, Obes. Metab. **25**, 1147 (2023)
13. C. Farrand, G. MacGregor, N.R.C. Campbell, J. Webster, *Potential use of salt substitutes to reduce blood pressure*. J. Clin. Hypertens. **21**, 350 (2019)
14. A. Brand, M. E. Visser, A. Schoonees, C. E. Naude, *Replacing salt with low-sodium salt substitutes (LSSS) for cardiovascular health in adults, children and pregnant women*, Cochrane Database Syst. Rev. **2022**, (2022)
15. R. Ariyanto, A. G. Dwi Kartika, *Pengaruh Perbedaan Metode Pembuatan Garam Sehat Rendah Natrium Terhadap Kadar NaCl, Air dan Sodium*, Juv. Ilm. Kelaut. dan Perikan. **3**, 32 (2022)
16. S. Redjeki, D. F. A. Muchtadi, M. R. A. Putra, *Garam Sehat Rendah Natrium Menggunakan Metode Basah*, J. Tek. Kim. **14**, 63 (2020)
17. S. Redjeki, J. Naibaho, M. T. Setiyono, *Low Sodium Healthy Salt by Dry Methods*, J. Phys. Conf. Ser. **1569**, (2020)
18. D. Thomas, *Costs, benefits, and adoption of additive manufacturing: a supply chain perspective*, Int. J. Adv. Manuf. Technol. **85**, 1857 (2016)
19. S. Polez *et al.*, *A simplified and efficient process for insulin production in Pichia pastoris*, PLoS One, **11**, 1 (2016)
20. M. Javaid, A. Haleem, R. P. Singh, R. Suman, E. S. Gonzalez, *Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability*, Sustain. Oper. Comput. **3**, 203 (2022)
21. K. Jayathilakan, K. Sultana, K. Radhakrishna, A. S. Bawa, *Utilization of by-products and waste materials from meat, poultry and fish processing industries: A review*, J. Food Sci. Technol, **49**, 278 (2012)
22. R. Rupert, K. F. Rodrigues, V. Y. Thien, W. T. L. Yong, *Carrageenan From Kappaphycus alvarezii (Rhodophyta, Solieriaceae): Metabolism, Structure, Production, and Application*, Front. Plant Sci. **13**, (2022)
23. S. Lomartire, J. C. Marques, A. M. M. Gonçalves, *An Overview of the Alternative Use of Seaweeds to Produce Safe and Sustainable Bio-Packaging*, Appl. Sci, **12**, (2022)
24. Rhein-Knudsen, N., Ale, M.T., Ajalloueian, F., Yu, L., Meyer, A.S.: Rheological properties of agar and carrageenan from Ghanaian red seaweeds. Food Hydrocoll. **63**, 50 (2017).
25. M. M. A. Fisheries, *Kelautan dan Perikanan dalam Angka tahun 2020 (Maritime Affairs and Fisheries in Figures 2020)*, Jakarta, (2021)
26. N. S. A. Indonesia, *Garam konsumsi beryodium (SNI 3556:2016)*, https://www.bsn.go.id/, (2016)
27. M. Bressan, E. Campagnoli, C. G. Ferro, V. Giaretto, *A Mass Balance-Based Method for the Anaerobic Digestion of Rice Straw*, Energies, **16**, 1 (2023)
28. S. W. Baertschi, B. W. Pack, C. S. H. Hyzer, M. A.

 https://doi.org/10.1051/bioconf/202414601002

Nussbaum, Assessing mass balance in pharmaceutical drug products: New insights into an old topic, TrAC - Trends Anal. Chem, **49**, 126 (2013)

29. M. A. Rosen, H. A. Kishawy, Sustainable manufacturing and design: Concepts, practices and needs, Sustainability, **4**, 154 (2012)
30. X. Chen, M. Despeisse, B. Johansson, *Environmental sustainability of digitalization in manufacturing: A review*, Sustain, **12**, 1 (2020)
31. L. Lima, E. Trindade, L. Alencar, M. Alencar, L. Silva, Sustainability in the construction industry: A systematic review of the literature, J. Clean. Prod., **289**, 125730 (2021)
32. K. Makenji, Mechanical methods for recycling waste composites, Manag. Recycl. Reuse Waste Compos., 217 (2009)
33. M. Sarvar, M. M. Salarirad, M. A. Shabani, Characterization and mechanical separation of metals from computer Printed Circuit Boards (PCBs) based on mineral processing methods, Waste Manag, **45**, 246 (2015)
34. S. P. Pudasaini, J. T. Fischer, *A mechanical model for phase separation in debris flow*, Int. J. Multiph. Flow, **129**, 103292 (2020).
35. Subaryono, R. Kusumawati, *Quality of Eucheuma cottonii seaweed cultivated in Lampung waters*, IOP Conf. Ser. Earth Environ. Sci, **404**, (2019)
36. R. Z. Utama, T. Handayani, *Suitability between Ocenography and Seaweed (Eucheuma cottonii) Cultivation Potential in Tidung Island with Geographic Information System (GIS)*, E3S Web Conf. **73**, 1 (2018)
37. F. Weinberger, T. Paalme, S. A. Wikström, Seaweed resources of the Baltic Sea, Kattegat and German and Danish North Sea coasts. Bot. Mar, **63**, 61 (2020)
38. S. Maneein, J. J. Milledge, B. V. Nielsen, P. J. Harvey, *A review of seaweed pre-treatment methods for enhanced biofuel production by anaerobic digestion or fermentation*, Fermentation, **4**, (2018)
39. R. H. Charlier, C. W. Finkl, A. Krystosyk-Gromadzinska, *Throw it overboard: A commentary on coastal pollution and bioremediation*, J. Coast. Res. **28**, 881 (2012)
40. D. Valderrama, J. Cai, N. Hishamunda, N. Ridler, *Social and economic dimensions of carrageenan seaweed farming: a global synthesis*, 2013, p. 5–59
41. National Standardization Agency of Indonesia, *Garam diet* (SNI 8208:2016), Jakarta, (2016)
42. M. F. Agustin, A. G. D. Kartika, M. Effendy, *Maflahah Program Studi Ilmu Kelautan, I., Kelautan dan Perikanan*, J. Pertanian, **1**, 468 (2020).