MethodsX 13 (2024) 102803

Contents lists available at ScienceDirect

MethodsX

journal homepage: www.elsevier.com/locate/methodsx

Geomembrane-based salt production method to increase the quantity and quality of small-scale salt producer

Gunarso Wiwoho [a], Imade Yoga Prasada [b,*]

[a] Study Program of Management, Faculty of Economics and Business, Universitas Putra Bangsa, Indonesia
[b] Study Program of Agribusiness, Faculty of Science and Technology, Universitas Putra Bangsa, Indonesia

ARTICLE INFO

Method name:
Geomembrane-based salt production method

Keywords:
Salt production
Small-scale salt producer
Geomembrane
Salt crystallization pond

ABSTRACT

An appropriate salt production methods must be implemented to increase salt production's quantity and quality. This paper was prepared to introduce and demonstrate a new method, namely a geomembrane-based salt production method, which can contribute directly to increasing the quantity and quality of people's salt production. This method can be applied quickly with simple equipment, so this method is easy to replicate in various salt production center areas. The results of statistical tests directly show that there is a fundamental difference between the quantity and quality of salt produced by salt farmers using conventional salt production methods and geomembrane-based salt production methods, where geomembrane-based salt production methods are capable of producing much higher quantities of salt production with better quality.

- The geomembrane-based salt production method is easy to implement because it uses simple equipment and can be made independently by salt farmers.
- Using a geomembrane in this method can prevent leaks in the salt crystallization pond and optimize heat from solar energy to optimize the quantity of salt production.
- This method prevents direct contact of seawater with soil. The effect is that the quality of salt produced from geomembrane-based salt production methods is higher than conventional salt production methods.

Specifications table

Subject area:	Food Science
More specific subject area:	Salt production
Name of your method:	Geomembrane-based salt production method
Name and reference of original method:	Rochwulaningsih Y, Sulistiyono ST, Utama MP, Masruroh NN, Rukayah S, Efendy M, et al. Traditional knowledge system in palung salt-making in Bali Island. J Ethn Foods. 2019;6(1):10. Available from: 10.1186/s42779-019-0018-2
Resource availability:	Reservoir ponds, evaporation ponds, salt crystallizers, solid cylinders, trenching tools, wooden stakes, geomembranes

Method details

The geomembrane-based salt production method is a salt production method that utilizes solar energy to process seawater to form salt crystals. This method is an improvement of the conventional method of salt production where the salt crystallization pond is lined with a layer of geomembrane to avoid direct contact of seawater with the ground during the salt crystallization process, whereas

* Corresponding author.
E-mail address: imade.yogap@gmail.com (I.Y. Prasada).

https://doi.org/10.1016/j.mex.2024.102803
Received 16 January 2024; Accepted 12 June 2024
Available online 13 June 2024

in the conventional salt production method, the salt crystallization pond is deliberately designed, directly on the ground [1]. This difference will directly affect the quantity and quality of salt farmers produce.

The geomembrane-based salt production method is considered to have several advantages, namely being able to minimize leaks in the embankments and bottom of crystallization ponds due to marine biota such as shellfish and sea snails, so that the quantity of salt production can be increased [2]. In addition, crystallization ponds that are not in direct contact with the ground cause salt production to have low levels of pollutants. Furthermore, the geomembrane layer can optimize the heat from solar energy received by the crystallization pond [3,4] so that the salt formation process becomes faster and the salt's NaCl content can be adequately increased. The geomembrane-based salt production method has one stage of method adjustment compared to the conventional method, where in the geomembrane-based salt production method there is a stage of installing a geomembrane which will become the base of the salt crystallization pond.

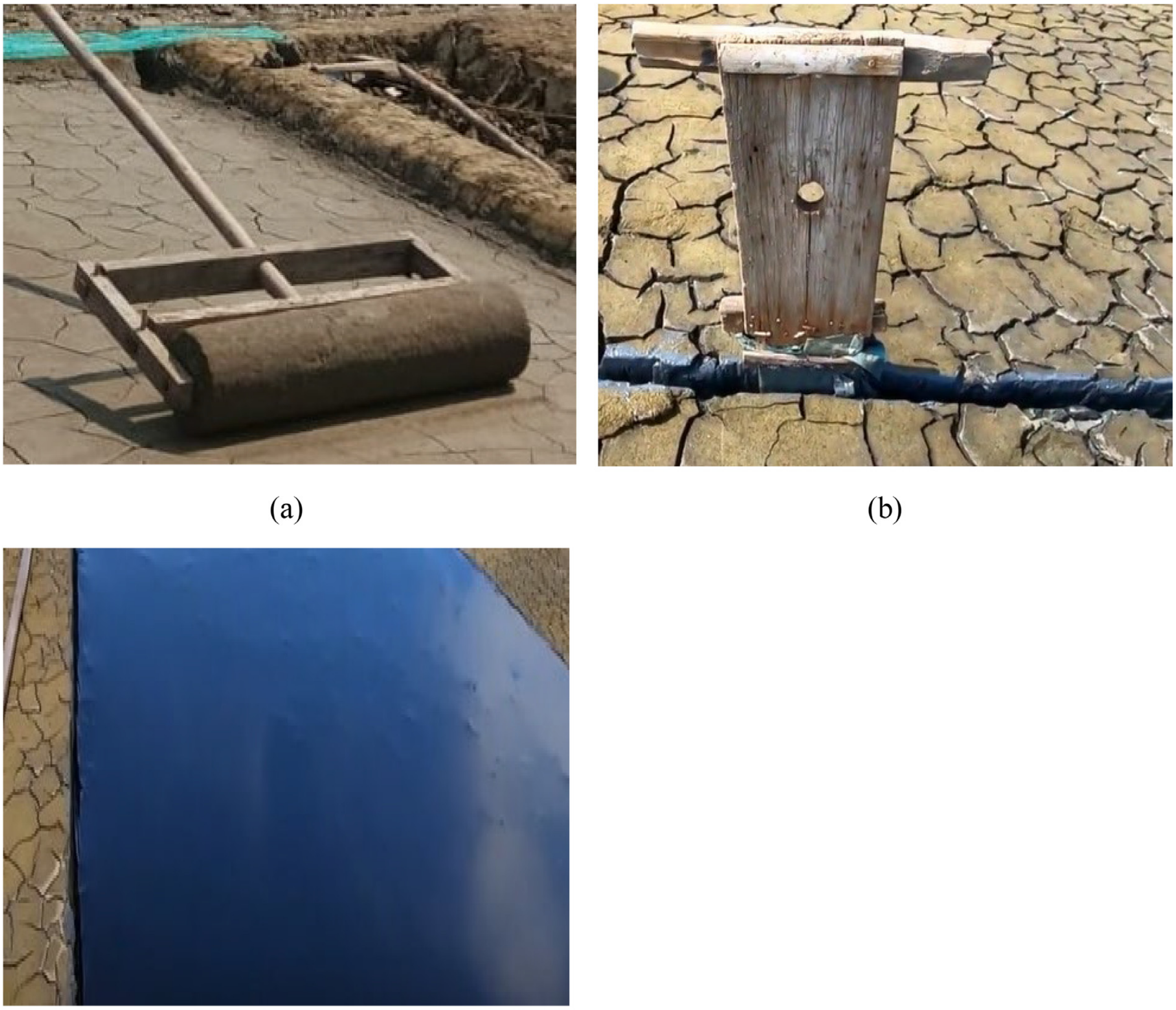
The application of this method depends on the availability of the geomembrane installed in the salt crystallization pond. Apart from that, the geomembrane specifications will also affect the resistance of the salt crystallization pond to marine biota, which can easily penetrate the geomembrane [5,6]. Furthermore, it is also necessary to ensure that the stages of installing the geomembrane layer are carried out correctly (there are no folded geomembrane layers) so that the use of geomembrane in the crystallization pond can be optimized to obtain harvests with superior quantity and quality.

Several stages must be carried out to implement a geomembrane-based salt production method. The first stage is preparing the equipment to install the geomembrane in the salt crystallization pond. These equipment are:

1. Solid cylinder, used to level the soil in salt crystallization ponds. The solid cylinder used in practice is a simple tool made independently by salt farmers using wood, bamboo, iron and cement (Fig. 1a). The size of this tool varies greatly between salt farmers. On average, this tool weighs 1 quintal with a tube height of 1 m;
2. The trench-making tool is used to make small trenches to connect geomembranes. Salt farmers made small trench-making tools directly using leftover wood from building materials no longer used (Fig. 1b). This tool has the characteristic of forming the letter "V" at the bottom with tapered ends. The size of this tool varies greatly among salt farmers in Indonesia because it is made from simple materials and adapted to the ease and practicality of the tool by each salt farmer;
3. Wooden stakes are used to lock the geomembrane installed in the crystallization pond. The stakes for installing the geomembrane are made from bamboo or other wood with sharp ends, which will then be driven into the ground through the geomembrane. These stakes are installed with the aim that gusts of sea breeze do not easily blow away the geomembrane layer;
4. Geomembrane as the bottom layer of the salt crystallization pond. The recommended geomembrane for salt crystallization ponds is a minimum thickness of 0.5 mm. A lower thickness can increase the risk of geomembrane leakage, thereby hampering the salt production process in the crystallization pond (Fig. 1c). Choosing geomembrane specifications in the smallholder salt production process is very important because it is related to the costs and benefits that salt farmers will obtain. The use of thick geomembrane results in a longer usage period. A thick geomembrane has relatively better resistance than a thinner one. However, the use of thick geomembrane also directly impacts increasing production costs that farmers must incur.

Once the equipment is available, the next stage is cultivating the land used as a salt crystallization pond using a geomembrane-based salt production method. Geomembrane installation begins with preparing the land used as a salt crystallization pond. These stages include:

1. Make ripening of the salt crystallization pond
The construction of embankments can be done manually by salt farmers. The embankment in the crystallization pond has an essential role as a barrier between the evaporation pond and the reservoir pond. Leaks in the embankment can make it difficult for salt crystals to form, and the NaCl content of the resulting salt will be lower. The embankment construction takes 2-3 days with 2-3 people for a crystallization pool measuring 1000 m^2. Wider crystallization pools require a larger number of people and a longer number of days.
2. Level the ground in the crystallization pond
The land in the crystallization pond must then be leveled to facilitate the salt harvesting process. Land leveling is done with the help of a solid cylindrical tool. This stage is carried out repeatedly using a solid cylinder until the soil in the crystallization pond is completely solid and even. The average time needed to complete this stage is between 3 and 4 days with a workforce of 1 to 2 people for a salt crystallization pond area of 1000 m^2. This stage is one of the most crucial in the geomembrane-based salt production process. Several things underlie this statement. First, using geomembrane requires a flat pool bottom, so the geomembrane installation process becomes easier and neater. This will make the salt harvesting process easier later. Second, geomembrane is a layer that is easily torn, especially the use of geomembrane with a thin layer (layer thickness below 0.5 mm) so that an uneven pool bottom can increase the risk of geomembrane leaks during salt production.
3. Installation of the geomembrane layer
After the soil layer in the crystallization pond is solid and even, the next stage is installing the geomembrane layer. Geomembrane layers generally have a size of 6 m x 50 m per roll, so installation on large areas requires more than one roll of geomembrane. Geomembrane installation begins with measuring the area of the crystallization pond. This measurement is carried out to determine the number of geomembrane rolls needed to cover the entire surface of the crystallization pond. After that, a small trench was made according to the size of the geomembrane (Fig. 2a). This trench connects one geomembrane to another so that the entire surface of the crystallization pond is entirely covered by a layer of geomembrane (Fig. 2b).



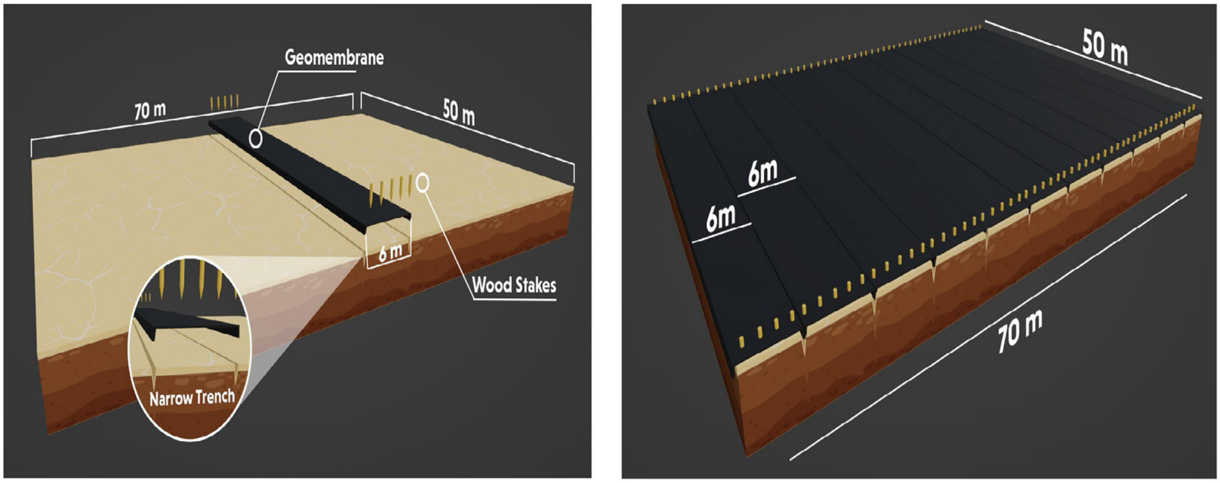
(a) (b) (c)

Fig. 1. (a) Solid cylinder, (b) Trench-making tools, (c) Geomembranes.

The geomembrane connection is carried out by inserting the edge of the geomembrane into the trench that has been made. Then, the trench is pressed with a footstep to make the trench tighter and prevent water leaks from the trench. This step is carried out repeatedly until the entire surface of the salt crystallization pond is covered by a layer of geomembrane (Fig. 2b). Finally, on the embankment, the geomembrane layer is locked using the wooden stakes provided, and then the salt crystallization pond is ready for use.

Once the crystallization pond is ready, the salt production process using the geomembrane-based salt production method can be carried out. The salt production begins by channeling seawater into a reservoir pond (Fig. 3). The pond stores young sea water (sea water with low salt content). Apart from having a low salt content (average salt content of 3 %), sea water at this stage also has a characteristic cloudy color because it is mixed with soil or mud particles. Sea water enters the reservoir pool assisted by windmill power, making the production process more cost-effective. The reservoir pool holds sea water for approximately 4–7 days to increase the salt content of the sea water through the evaporation process. This pool's sea water salt content is targeted at 3.5 %–4 %.

After reaching the salt level, the sea water from the reservoir pool will flow into the evaporation pool. In evaporation ponds, the salt content of sea water is increased gradually from the first evaporation pond to the last evaporation pond. The salt content in sea water that is expected from the evaporation process of sea water in the pool is 19 %–25 % or, commonly referred to as old water (seawater with a high salt content). When the target salt content has been met in the evaporation pond, the old water will flow into the crystallization pond coated with a geomembrane layer. Salt crystals will begin to form when the old water in the salt crystallization pond is 2-3 days old, and after that, the salt is ready to be harvested.



(a) (b)

Fig. 2. (a) Making a small trench to connect one geomembrane to another, (b) Salt crystallization pond that has been entirely covered by geomembrane.

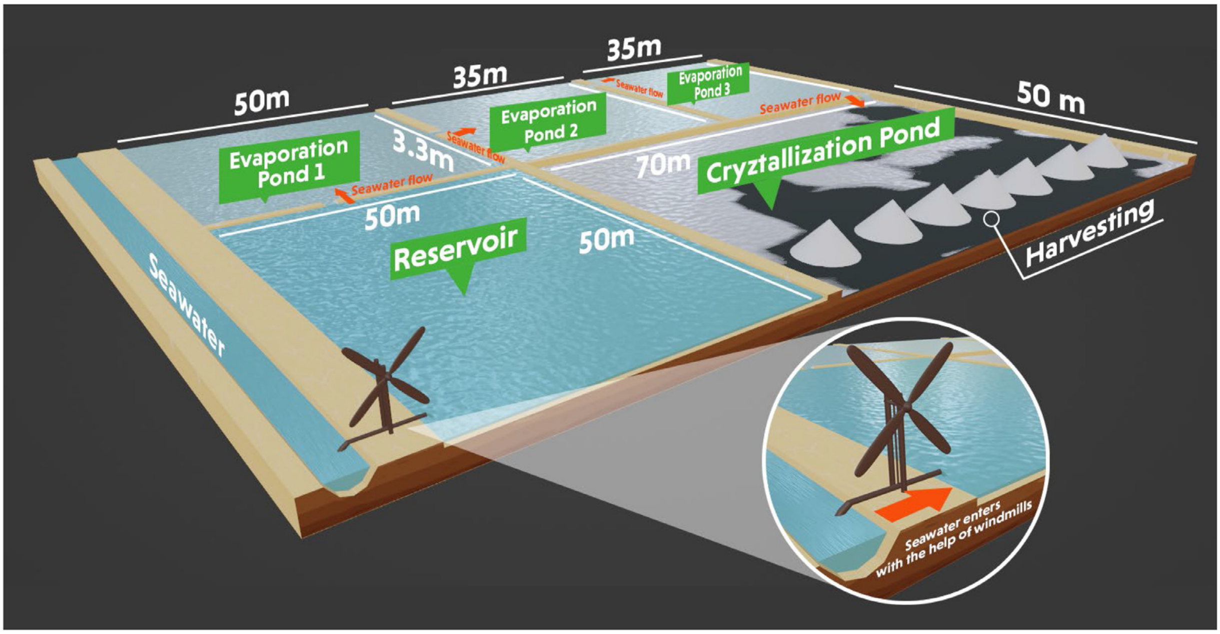


Fig. 3. The salt production flow uses a geomembrane-based salt production method.

Next, we carried out an evaluation to show the differences in the performance of people's salt production that uses geomembrane and those that do not. Several indicators are the main focus that can show the positive impact of using geomembrane in the process of smallholder salt production, namely the quantity and quality of production [7,8], the length of time for salt production and the number of harvests [9], the use of labor [10,11], and the income level of salt farmers [12,13]. This evaluation was analyzed using the independent sample *t*-test statistical test method. We took a sample of 154 salt farmers, of which 68 used conventional methods and 86 used geomembrane-based salt production methods.

The results of the analysis show that the geomembrane-based salt production method can produce higher production results than conventional methods. Salt produced through conventional methods can only produce an average of 1280.9712 kg per hectare per harvest (Table 1). This value is much lower when compared to the geomembrane-based salt production method, which can produce salt with a quantity of 1908.2791 kg per hectare per harvest. Statistically, the *t*-test probability is 0.0008, lower than the alpha level of 1 %, meaning there is a significant difference between conventional and geomembrane-based salt production methods.

Table 1
T-test of salt production using conventional and geomembrane-based salt production methods.

Variable	Obs.	Average production (kg/ha)	Std. err.	Std. dev.
Conventional	68	1280.97	81.00	667.94
Geomembrane-based salt production	86	1908.28	149.80	1389.20
t-test				−3.42
Prob.				0.00

Source: Primary data analysis, 2024.

Table 2
T-test for the length of time for salt production using conventional methods and geomembrane-based salt production methods.

Variable	Obs.	Production time (days)	Std. err.	Std. dev.
Conventional	68	5.08	0.24	1.98
Geomembrane-based salt production	86	2.41	0.11	1.03
t-test				10.77
Prob.				0.00

Source: Primary data analysis, 2024.

Table 3
T-test for the number of salt harvests per season using conventional methods and geomembrane-based salt production methods.

Variable	Obs.	Number of harvests (times/season)	Std. err.	Std. dev.
Conventional	68	33.49	2.41	22.35
Geomembrane-based salt production	86	47.12	3.54	29.26
t-test				−3.28
Prob.				0.00

Source: Primary data analysis, 2024.

Table 4
T-test of labor use for salt production using conventional methods and geomembrane-based salt production methods.

Variable	Obs.	Labor (man-day)	Std. err.	Std. dev.
Conventional	68	208.17	15.36	126.66
Geomembrane-based salt production	86	161.89	14.01	130.00
t-test				2.21
Prob.				0.02

Source: Primary data analysis, 2024.

The higher production using the geomembrane-based salt production method is due to the characteristics of the geomembrane which can optimally absorb solar heat, so that more salt crystals are formed. Furthermore, using geomembrane in the salt production process causes the seawater evaporation process faster, meaning that the time required for the salt production process is shorter than conventional methods (Table 2.).

Salt production using conventional methods takes 5.08 days from the time seawater enters the crystallization pond until salt crystals that are ready to be harvested are formed. This figure is much greater than the geomembrane-based salt production method which requires a production time of 2.41 days from the time seawater enters the salt crystallization pond. This shows that the geomembrane-based salt production method can shorten the salt production process. In short, production time influences the number of harvest days that farmers can harvest. Salt farmers using conventional methods can only harvest salt 33.49 times on average, while farmers using geomembrane-based salt production methods are able to harvest 47.12 times per season (Table 3).

Another indicator, namely the labor use indicator, also shows that the geomembrane-based salt production method can minimize the use of labor in the smallholder salt production process (Table 4). The use of conventional labor methods is 208.17 man-day. This figure is much greater than the use of labor in the geomembrane-based salt production method which is only 161.89 man-day. The use of labor in the salt production process includes the use of labor to create salt pond embankments, level the land, install and maintain windmills, create water channels, install geomembranes (especially for geomembrane-based production methods), produce and harvest salt, and market salt.

The geomembrane-based salt production method uses less labor for the salt production and harvesting process compared to conventional methods (although there is additional labor used for geomembrane installation with an average labor force of 5.73 man-day). In the conventional method, the production and harvesting process requires more labor because salt must be washed

Table 5
T-test of income of salt farmers using conventional methods and geomembrane-based salt production methods.

Variable	Obs.	Income (IDR)	Std. err.	Std. dev.
Conventional	68	4.43e+07	5125.23	4234.34
Geomembrane-based salt production	86	6.04e+07	3920.98	3598.45
t-test				−2.54
Prob.				0.01

Source: Primary data analysis, 2024.

Table 6
T-test of salt quality using conventional and geomembrane-based salt production methods.

Variable	Obs.	Average NaCl concentration (%)	Std. err.	Std. dev.
Conventional	68	88.77	0.39	3.21
Geomembrane-based salt production	86	92.03	0.49	4.59
t-test				-2,18
Prob.				0,03

Source: Primary data analysis, 2023.

before being harvested to remove dirt or soil particles carried in the salt crystals. The conventional method for the salt production and harvesting process requires a workforce of 102.12 man-day, while the geomembrane-based salt production method only requires a workforce of 66.27 man-day.

The use of geomembrane-based salt production methods has an impact on increasing the costs that farmers have to pay to provide geomembrane. Salt farmers who use geomembrane-based salt production methods must purchase geomembrane for use in salt crystallization ponds. A salt crystallization pond with a size of 1000 m^2 requires 4 rolls of geomembrane measuring 6 m x 50 m and a thickness of 0.5 mm at a price of IDR 2279,400 per roll. However, the selling price of salt produced using the geomembrane-based salt production method is much higher than the conventional method, so the overall income of farmers using the geomembrane-based salt production method is higher than the conventional method (Table 5).

The selling price of salt using the geomembrane-based salt production method is higher than the conventional method due to the high quality of the salt produced using this method. The quality of the salt produced can be determined by using an indicator for the NaCl content contained in the salt. The higher the NaCl content, the higher the quality of the salt produced. The price of superior-quality salt can reach IDR 1900 per kg, while low quality salt can only be sold for IDR 400 per kg. The analysis results show that the NaCl content in the salt produced using the geomembrane-based salt production method is higher than the conventional method (Table 6).

Salt produced using the geomembrane-based salt production method has an average NaCl content of 92.03 %, different from salt produced using conventional methods, where the average NaCl content contained in the salt is only 88.77 %. The statistical analysis results show that the *t*-test probability value is 0.03, where this value is lower than the alpha level of 5 %, thus indicating that statistically, the salt produced through the geomembrane-based salt production method has a higher NaCl content than the salt produced and produced through conventional methods. These results prove that the geomembrane-based salt production method can increase the quantity and quality of salt production compared to conventional methods [1]. Using simple equipment and relatively easy application of methods with great benefits for salt farmers are the main advantages of the geomembrane-based salt production method. This can also encourage this method to be replicated and applied well in various areas of salt production centers that rely on solar thermal energy.

Ethics statement

We confirm that every aspect of the work included in this manuscript involving human respondents to test the methods developed has been carried out with ethical approval from all relevant bodies and that such approval is acknowledged in the manuscript.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Imade Yoga Prasada reports financial support was provided by Ministry of Education Culture Research and Technology. Imade Yoga Prasada reports a relationship with Ministry of Education Culture Research and Technology that includes: funding grants.

CRediT authorship contribution statement

Gunarso Wiwoho: Conceptualization, Data curation, Formal analysis, Methodology, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Imade Yoga Prasada:** Conceptualization, Formal analysis, Methodology, Resources, Funding acquisition, Writing – original draft.

Data availability

Data will be made available on request.

Acknowledgments

The author would like to thank the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia for providing financial support to the research team to develop the competitiveness of smallholder salt businesses in Indonesia.

References

[1] Y. Rochwulaningsih, S.T. Sulistiyono, M.P. Utama, N.N. Masruroh, S. Rukayah, M. Efendy, et al., Traditional knowledge system in palung salt-making in Bali Island, J. Ethn. Foods 6 (1) (2019) 10 Available from, doi:10.1186/s42779-019-0018-2.
[2] S.M. Sharma, K. Tian, B. Tanyu, Evaluation of Atactic Polypropylene (APP) geomembranes used as liners for salt ponds, Geotext. Geomembr. 51 (1) (2023) 165–178 Available from https://www.sciencedirect.com/science/article/pii/S0266114422001157 .
[3] F.L. Lavoie, M. Kobelnik, C.A. Valentin, da Silva Tirelli ÉF, M. de Lurdes Lopes, J. Lins da Silva, Environmental protection with HDPE geomembranes in mining facility constructions, Constr. Mater. 1 (2021) 122–133.
[4] F.L. Lavoie, C.A. Valentin, M. Kobelnik, J. Lins da Silva, M.D. Lopes, HDPE geomembranes for environmental protection: two case studies, Sustainability 12 (2020) 1–19.
[5] N.R.C. Campbell, P.K. Whelton, M. Orias, R.D. Wainford, F.P. Cappuccio, N. Ide, et al., 2022 World Hypertension League, resolve to save lives and international society of hypertension dietary sodium (salt) global call to action, J. Hum. Hypertens. 37 (6) (2023) 428–437 Available from, doi:10.1038/s41371-022-00690-0.
[6] S. Bhat, M. Marklund, M.E. Henry, L.J. Appel, K.D. Croft, B. Neal, et al., A systematic review of the sources of dietary salt around the world, Adv. Nutr. 11 (3) (2020) 677–686 Available from https://www.sciencedirect.com/science/article/pii/S2161831322002927 .
[7] A. Prakash, S.K. Jha, K.D. Prasad, A.K. Singh, Productivity, quality and business performance: an empirical study, Int. J. Product. Perform. Manag. 66 (1) (2017) 78–91 Available from, doi:10.1108/IJPPM-03-2015-0041.
[8] S. Handoyo, H. Suharman, E.K. Ghani, S. Soedarsono, A business strategy, operational efficiency, ownership structure, and manufacturing performance: the moderating role of market uncertainty and competition intensity and its implication on open innovation, J. Open Innov. Technol. Mark Complex 9 (2) (2023) 100039 Available from https://www.sciencedirect.com/science/article/pii/S2199853123001415 .
[9] A. Ansar, A.N. Ahmad Yahaya, A.A. Kamil, R. Sabani, M. Murad, S. Aisyah, A new innovative breakthrough in the production of salt from bittern using a spray dryer, Heliyon 8 (10) (2022) e11060 Available from https://www.sciencedirect.com/science/article/pii/S2405844022023489 .
[10] G. Damioli, V. Van Roy, D. Vertesy, The impact of artificial intelligence on labor productivity, Eurasian Bus. Rev. 11 (1) (2021) 1–25 Available from, doi:10.1007/s40821-020-00172-8.
[11] N.P. Tran, D.H. Vo, Human capital efficiency and firm performance across sectors in an emerging market, Cogent Bus. Manag. 7 (1) (2020) 1738832 Jan 1Available from, doi:10.1080/23311975.2020.1738832.
[12] S. Suhadak, K. Kurniaty, S.R. Handayani, S.M. Rahayu, Stock return and financial performance as moderation variable in influence of good corporate governance towards corporate value, Asian J. Account. Res. 4 (1) (2019) 18–34 Jan 1Available from, doi:10.1108/AJAR-07-2018-0021.
[13] W. Affes, A. Jarboui, The impact of corporate governance on financial performance: a cross-sector study, Int. J. Discl. Gov. 20 (4) (2023) 374–394 Available from, doi:10.1057/s41310-023-00182-8.