

Air Circulation Drying Technology: Entrepreneurial Strategy for the Tamban Fish Crackers Industry

*Fitrialdi Fitrialdi**, *Feby Sarianty*, *Sarmian Sitanggang*, *Fathussalamiah Fathussalamiah*, *Encik Abdulhajar*, and *Zaitun Zaitun*

Magister of Paedagogy Faculty of Teacher Training and Education, Raja Ali Haji Maritime University, Tanjungpinang 29411, Indonesia

Abstract. This research evaluates the use of drying technology with air circulation to improve the production efficiency of tamban fish crackers. This research uses a quantitative experimental design to evaluate the efficiency of drying technology with air circulation compared to traditional drying methods. The research results show that this technology is able to reduce drying time from 7 hours to 5 hours resulting in more consistent product quality in terms of moisture and texture. This technology has operational flexibility and does not depend on weather conditions, so production can be carried out throughout the year. Drying technology with air circulation offers an effective solution to increase the productivity and competitiveness of the tamban fish cracker industry.

1 Introduction

The seafood processing industry plays an important role in enhancing the economic resilience of coastal and island communities by processing fish and seafood products into high-value items such as anchovies and fish crackers. This transformation not only reduces waste from the by-products of seafood, which are rich in protein and healthy fatty acids, but also creates new bio-products to enhance the performance and sustainability of the local economy [1]. Additionally, small-scale fisheries and aquaculture contribute to food sovereignty by providing essential nutrition and livelihoods, while also fostering social capital and equitable resource management [2]. The projected significant growth of the blue economy underscores the importance of sustainable practices in fisheries and aquaculture that can reduce poverty and support community resilience, especially after disruptions such as the COVID-19 pandemic [3,4]. Through the diversification of distribution strategies and the enhancement of local markets, these communities are expected to become more resilient in facing economic shocks and to improve overall well-being [5].

Innovation in processing techniques is crucial to enhancing competitiveness in the face of global market challenges and supply chain disruptions. The integration of blockchain technology into supply chain management can significantly reduce production costs and enhance capital chain efficiency, thereby promoting the development of sustainable companies [6]. The application of deep learning methods in supply chain management enables rapid data analysis, providing a competitive advantage by optimizing operations and addressing complex SCM issues [7]. On the other hand, the adoption of additive manufacturing in traditional processes such as injection molding can lead to a cost reduction of 80-90% and a decrease in production lead time of 60-70% [8]. Collectively,

* Corresponding author: fitrialdimr@gmail.com

these innovations contribute to building a resilient and adaptive supply chain to ongoing challenges, particularly in sectors such as agri-food, where strategic innovation is crucial for sustainability [9].

The NEPTUNE project underscores the importance of environmentally friendly innovation and circular economy principles in enhancing resource efficiency and sustainability in the seafood sector. By promoting environmentally friendly innovation approaches and eco-labeling, this project aims to address socio-ecological challenges and facilitate the transition towards a circular economy, in line with the UN Sustainable Development Goals and European policies [10]. Valorization of seafood waste into biodegradable packaging materials exemplifies the potential of the circular economy in transforming waste into valuable resources, thereby reducing environmental impact [11]. Additionally, the shift to bio-based materials in aquaculture, such as biodegradable ropes, emphasizes the importance of sustainable practices to minimize marine waste and support recycling [12]. Additionally, the Marine Stewardship Council certification framework supports sustainable fisheries management, which can have a positive impact on the socio-economic conditions of communities [13]. By integrating traditional practices and collaborative management approaches, as seen in Samoa, this industry can also support food sovereignty and social equity, which strengthens community resilience [2].

Fish crackers are a high-value processed product made from fish, utilizing the abundant availability of fish raw materials in coastal areas. Its high durability enhances storage and distribution capabilities, making it more preferred than fresh fish, which is easily perishable [14]. The transformation of by-products from marine resources into fish crackers not only reduces waste but also adds economic value, potentially increasing community income and strengthening the local economy [1,15]. In addition, fish protein hydrolysates from by-products such as bones and fish scraps can enhance the nutritional profile of crackers, making these products suitable for marketing at both national and international levels [16]. The valorization of these fish by-products aligns with sustainability goals, promoting the efficient use of resources while expanding the market potential for seafood products [17].

Sun drying has a major drawback of being weather-dependent, which makes the drying time unpredictable and the product quality inconsistent. This traditional drying method can also cause oxidation and protein degradation, negatively impacting the texture and nutritional value of fish products [18]. As an alternative, modern drying methods are able to better maintain the structural integrity of fish proteins, resulting in higher quality products, better color, and lower oxidation [18]. Additionally, this technique not only reduces drying time but also lowers energy consumption, thereby increasing production efficiency [19]. Modern drying methods, such as spray drying and hot air drying, have been proven to improve product quality by enhancing water solubility and reducing lipid oxidation, which is crucial for maintaining the integrity of fish-based products [20]. Additionally, vacuum packaging techniques can extend the shelf life of products by inhibiting the growth of spoilage bacteria, thereby helping to maintain the quality of the final product [14]. The integration of advanced drying technology not only reduces the negative impact of environmental factors but also supports sustainability goals by utilizing low-value fish species and reducing food waste [20]. Therefore, the application of modern drying methods is crucial to enhance the quality and reliability of fish cracker production.

The seafood processing industry faces significant challenges in utilizing marine by-products, especially in the context of fish cracker drying. Currently, many industries still rely on traditional processing techniques that tend to overlook the potential of by-products such as fish heads, skins, and entrails, which are rich in valuable nutrients like protein and healthy fats [1]. The lack of innovation in utilizing these by-products indicates a gap in the application of modern technology that could transform them into high-value goods [21].

The development of a sustainable closed-loop supply chain has the potential to enhance efficiency in waste management and optimal resource utilization in the seafood sector [22]. Innovation in preservation techniques, such as the use of biodegradable films and biopreservation methods, can extend the shelf life of products, thereby increasing their marketability and reducing waste [23].

Traditional fish processing and drying heavily rely on sunlight, leading to inconsistent drying times and frequently compromised product quality, thereby reducing the competitiveness of fish cracker products in the market. The application of solar-assisted drying technology, such as cylindrical solar dryers, has proven to significantly improve drying efficiency and produce more stable product quality, while also reducing drying time and energy costs [24]. Additionally, alternative preservation techniques, such as biodegradable coatings and superchilling methods, can extend the shelf life of seafood without compromising the sensory quality of the product [23]. Innovative approaches to utilizing seafood by-products can also enhance economic value and sustainability in aquaculture by transforming waste into more valuable products [1]. Overall, these technological advancements provide practical solutions to address the inefficiencies of traditional drying, thereby enhancing the quality and competitiveness of seafood products in the market.

The limitations in maintaining the nutritional quality and texture of fish-based products during the drying process can be overcome through the application of innovative technology. Traditional drying methods often lead to protein degradation and lipid oxidation, which damage the quality of the final product [25]. Pulsed Electric Field (PEF) technology has emerged as a promising non-thermal preservation method because it not only inactivates microorganisms but also accelerates the drying process, thereby enhancing nutrient retention [26]. Furthermore, the modification of fish protein with chitosan oligosaccharides has been proven to delay oxidation and improve functional characteristics, which greatly supports the enhancement of fish cracker quality [27]. Encapsulation techniques, such as spray drying, also show improved oxidative stability of fish oil, which is important for maintaining the nutritional integrity of fish products during storage [28]. Overall, these technological advancements enable fish-based products to achieve the high-quality standards needed to compete in the market.

Drying technology for fish-based products, especially fish crackers, faces significant challenges in maintaining quality and nutritional texture due to protein degradation and lipid oxidation. These issues impact the competitiveness of the products in both national and international markets. Various strategies have been proposed to address these challenges, including antioxidant delivery systems through innovative methods such as encapsulation and edible coatings, which are effective in reducing lipid oxidation [29]. Although technologies such as superchilling and high-pressure processing show potential for maintaining nutritional properties and texture without compromising quality [23], their application in the seafood industry is still limited, making the balance between innovation and consumer acceptance crucial for future development in fish product preservation.

The fish cracker industry can gain significant benefits from modern drying technologies, such as spray drying and hot air drying, which improve product quality while reducing energy consumption. Despite their advantages, these methods are underutilized, indicating the need for further research to optimize their application at various scales. The advantages of modern drying technology include quality preservation, where spray drying and freeze drying (FD) maintain the structural integrity of proteins better than traditional methods, resulting in superior product quality [18]. Additionally, energy efficiency can be achieved by applying optimized spray drying conditions, which reduce energy consumption while maintaining the desired product characteristics, as demonstrated in studies on fruit extracts [30]. Despite its great potential, the existing research gaps indicate the need for

comprehensive studies to explore specific parameters affecting drying efficiency and product quality in the fish cracker sector [18,31].

2 Methodology

This research uses an experimental design to evaluate the effectiveness of hot air drying and air circulation technology in the tamban fish cracker industry. The experimental research design was chosen to objectively compare the traditional drying method with the new drying technology used. Samples of tamban fish crackers processed with both methods were collected for final result analysis. Testing was conducted in the laboratory with strict variable control, including temperature and drying time. These variables are controlled to ensure valid and replicable results.

The main ingredient used in this study is fresh tamban fish, which is processed into crackers using traditional methods and new technology. The drying instruments include an automatic dryer with controlled air circulation and supporting equipment for measuring the moisture and texture of the final product. In addition, digital moisture meters are used to obtain accurate data on the moisture content of the products. These materials and instruments were selected based on their relevance to the research objectives in improving quality and production efficiency.

The research procedure begins with the drying process of tamban fish crackers using traditional methods and new technology alternately. Each method was tested under different environmental conditions, namely sunny and cloudy conditions, to assess the differences in product quality and operational flexibility. Drying time, humidity, and texture data were recorded and analyzed after each drying session was completed. The results of both methods were then compared to assess the superiority of the new technology in maintaining the quality of the final product. The entire procedure was carried out using standardized methods so that the results obtained could be compared objectively.

3 Results and Discussion

The research results show that the application of hot air drying and air circulation technology in the tamban fish cracker industry successfully reduced the drying time from 7 hours to 5 hours. This reduction in drying time directly impacts the improvement of production efficiency and product quality consistency, particularly in terms of moisture and texture. With the use of this technology, the final product's moisture can be maintained at an optimal level, resulting in a more stable product texture that meets the expected quality standards. This technology also has the advantage of operational flexibility, allowing the production process to be independent of weather conditions. Therefore, the production of tamban fish crackers can be carried out year-round without external weather disruptions, providing potential for sustainable business development for small and medium enterprises.

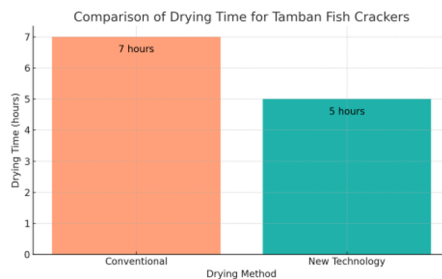


Fig. 1. Comparison of Drying Time

The application of hot air drying and air circulation technology in the production of tamban fish crackers shows a significant improvement in the efficiency of the drying process. Based on the data obtained, the drying time was reduced from 7 hours to 5 hours, providing a time efficiency of about 28.6%. The comparison graph of drying time between the conventional method and this new technology (Figure 1) shows a consistent reduction in time for each production cycle. This reduction in drying time allows for an increase in production capacity, enabling producers to manage more production cycles per day. In addition, the results of product quality testing show that the product's moisture can be optimally maintained at a level of 10-12%, resulting in a crispier and more durable texture of the crackers during storage.

Table 1. Comparison of Production Flexibility Based on Weather Conditions

Condition	Traditional Method	New Technology
Clear	Influenced (Slow)	Not Influenced
Cloudy/Rainy	Not Producing	Still Producing

The Table 1 shows that the new drying technology has significant advantages in operational flexibility compared to traditional methods that are vulnerable to weather influences. In sunny conditions, traditional methods often experience slowdowns, while the new technology continues to operate without interruption. In cloudy or rainy weather, traditional methods generally cannot be used due to their dependence on sunlight, which halts the production process. In contrast, new technology allows production to run smoothly, enabling the continuous production of tamban fish crackers without relying on weather conditions. This advantage has the potential to consistently increase production capacity throughout the year.

Table 2. Comparison of Product Quality

Parameter	Traditional Method	New Technology
Drying Time	7 Hours	5 Hours
Product Moisture	(13-15%)	(10-12%)
Product Texture	Less Stable	More Stable

This table summarizes the comparison of product quality between traditional methods and new drying technology. The new technology shows an improvement in product moisture consistency, with stable moisture levels in the range of 10-12%, while traditional methods tend to be variable at 13-15%. Additionally, the texture of the products produced by the new technology is more stable and meets the expected quality standards, compared to the less uniform texture of products from traditional methods. This efficiency not only improves the final product quality but also enhances the shelf life of the crackers during storage. Overall, this technology produces more consistent and high-quality products.

Another advantage of this technology is its flexibility, which is not dependent on weather conditions, unlike traditional drying methods that heavily rely on sunlight. The comparison matrix of production conditions shows that this drying technology can operate under various environmental conditions, whether in sunny, cloudy, or rainy weather. This provides significant added value for producers, especially in maintaining production stability throughout the year. In trials during the rainy season, the product maintained consistent quality, with no significant variations in moisture levels or texture. Another interesting finding is the reduction in operational costs related to fuel due to shorter drying times, making this technology a more energy-efficient and environmentally friendly option.

The integration of modern drying technology in the seafood processing industry significantly enhances the utilization of marine by-products, such as fish heads, skins, and offal, which are often overlooked despite being rich in nutrients. These advanced drying methods not only enhance drying efficiency but also facilitate the transformation of by-products into high-quality products such as fish crackers, thereby addressing gaps in resource utilization [1]. Research shows that by-products can be processed into valuable items, such as umami-rich seasoning powder from tilapia fillets, which demonstrate consumer preference and economic sustainability [32]. Furthermore, the valorization of by-products from crustacean and bivalve processing reveals their potential as raw materials for various high-value applications, in line with the principles of a circular economy [33]. Overall, the application of innovative drying technology contributes to sustainable resource management and the development of a closed-loop supply chain in the seafood industry [34,35].

The application of advanced drying technologies, such as hot air drying with air circulation, shows significant benefits in reducing drying time and improving product quality in the fish cracker industry. This method successfully reduced the drying duration from 7 hours to 5 hours, which not only saves energy but also improves moisture retention and texture consistency, essential factors for maintaining product quality [36]. Research shows that shorter drying durations also reduce protein degradation and lipid oxidation that can compromise product integrity [37]. Additionally, innovations such as hybrid microwave convective drying have shown that optimizing drying conditions can enhance the rehydration ratio and bioactive compounds in the final product [24]. This advancement underscores the importance of technological innovation in ensuring that seafood products meet global standards, thereby enhancing competitiveness in the international market [38] [39].

The operational flexibility of modern drying technology significantly enhances production capacity in industries such as fish crackers, as it does not depend on weather conditions like traditional drying methods that rely on sunlight. With independence from climate variability, this technology enables continuous operations, especially beneficial during bad weather, such as the rainy season, which often hampers production in conventional systems [24]. The ability to manage multiple production cycles each day contributes to the stability of the seafood supply chain, making it more effective in meeting market demand [24]. Additionally, the efficiency of modern drying technologies, such as microwave drying, has been proven to reduce drying time and energy consumption while maintaining product quality, which is crucial for maintaining industry competitiveness [40]. The integration of these drying technologies not only reduces risks associated with environmental factors but also optimizes operational efficiency and product quality [24] [40].

The fish cracker industry can utilize modern drying technologies such as spray drying and microwave convective drying, which are capable of reducing drying time and energy consumption while improving product quality. For example, research shows that optimal temperature and microwave power settings can reduce drying time and specific energy

consumption (SEC), such as in pumpkin slices with a drying time of about 47.38 minutes and an SEC of 30.87 MJ/kg [37]. Similarly, spray drying of *Morinda citrifolia* L. fruit extract with specific temperature settings and material ratios has been proven to maintain moisture content and antioxidant properties [30]. The spray drying method produces smaller and more soluble particles, which enhance the functional properties of food products such as surimi gel [41]. Therefore, further research on the application of this drying technique in the fish cracker industry can support product efficiency and quality [31] [42].

The application of modern drying technology in fish cracker production, particularly for small industries in coastal areas, offers significant opportunities to improve product quality and shelf life. Traditional drying methods often result in inconsistent quality and low storage stability, which can be addressed through innovative techniques. For example, biopolymer coatings have been shown to enhance drying efficiency while protecting bioactive compounds, which could potentially be applied to fish crackers [43]. Additionally, the use of micro-nano ozone bubbles in the production of pumpable ice slurry demonstrates superior preservation capabilities for seafood, offering a new method to maintain freshness during the production process [44]. Furthermore, the utilization of by-products from seafood processing has the potential to support sustainable practices and create high-value products, strengthening the economic viability for small-scale operations [33,1].

4 Conclusion

This research shows that the application of hot air drying technology with air circulation in the tamban fish cracker industry significantly improves product efficiency and quality. This technology successfully reduced the drying time from 7 hours to 5 hours, resulting in more consistent outcomes in terms of moisture and texture. The produced products have higher quality, with moisture maintained at optimal levels and texture stable according to industry standards. Additionally, this technology allows production to continue year-round without being dependent on the weather, providing flexibility and stability in production for industry players.

Modern drying technology also shows significant potential in supporting the sustainability of the seafood industry through waste reduction and optimization of by-product utilization. Processing often-overlooked fish by-products such as skin and bones can be transformed into high-value products, in line with the principles of an efficient and environmentally conscious circular economy. These findings not only add economic value but also support sustainable resource management, which is crucial in meeting global market demands.

Overall, the application of advanced drying technology in the fish cracker industry not only provides benefits in terms of product quality and production efficiency but also contributes to the development of an environmentally friendly and highly competitive industry. With the adoption of this technology, the tamban fish cracker industry can be more adaptive in facing supply chain challenges and market demand fluctuations. This implication shows that the use of modern drying technology is a strategic step in supporting sustainability and enhancing the local economy in the seafood processing sector.

References

1. S. A. Siddiqui et al., *Valuable Products*, **1** (2023).
2. B. Quimby et al., *Hum. Ecol.* **51**, 279 (2023).
3. L. S. Evans, P. M. Buchan, M. Fortnam, M. Honig, and L. Heaps, *Front. Polit. Sci.* **5**, (2023).

4. H. R. Bassett, S. Sharan, S. K. Suri, S. Advani, and C. Giordano, *Marit. Stud.* **21**, 173 (2022).
5. K. Carlson, T. Young, M. A. Centeno, S. A. Levin, and D. I. Rubenstein, *Environ. Res. Lett.* **16**, (2021).
6. L. Xiang and R. Hou, *Sustain.* **15**, (2023).
7. F. Hosseinnia Shavaki and A. Ebrahimi Ghahnavieh, *Applications of Deep Learning into Supply Chain Management*, Springer Netherlands **56**, (2023).
8. G. Tosello et al., *Int. J. Adv. Manuf. Technol.* **100**, 783 (2019).
9. S. Joshi, M. Sharma, B. Y. Ekren, Y. Kazancoglu, S. Luthra, and M. Prasad, *Sustain.* **15**, (2023).
10. J. Laso et al., *Sustain.* **14**, (2022).
11. Z. Zhao, Y. Li, and Z. Du, *Sustain.* **14**, 1 (2022).
12. L. Arantzamendi, M. Andrés, O. C. Basurko, and M. J. Suárez, *Rev. Aquac.* **15**, 1010 (2023).
13. O. Oloruntuyi, J. Barendse, M. Marriott, A. K. Gordon, and C. Montero-Castaño, *Front. Mar. Sci.* **10**, 1 (2023).
14. M. L. Lemos et al., *Vet. Sci.* **10**, (2023).
15. M. Taroncher, Y. Rodríguez-Carrasco, F. J. Barba, and M. J. Ruiz, *Int. J. Mol. Sci.* **24**, (2023).
16. J. Valcarcel, N. Sanz, and J. Vazquez, *Optimization of the Enzymatic Protein Hydrolysis*, (2020).
17. M. R. Hasan, J. A. Chaplin, P. B. Spencer, and M. Braccini, *Fish Fish.* **24**, 777 (2023).
18. P. Chen, Y. Qiu, S. Chen, Y. Zhao, Y. Wu, and Y. Wang, *Front. Nutr.* **9**, 1 (2022).
19. X. Fei Wu, M. Zhang, and B. Bhandari, *A novel infrared freeze drying (IRFD) technology*, **54**, (2019).
20. M. C. Gómez-Guillén, S. Pérez-García, A. Alemán, M. E. López-Caballero, C. G. Sotelo, and M. P. Montero, *Foods* **12**, (2023).
21. N. P. Nirmal and S. Maqsood, *Front. Nutr.* **9**, (2022).
22. M. Fasihi, R. Tavakkoli-Moghaddam, M. Hajiaghaei-Keshтели, and S. E. Najafi, *Environ. Sci. Pollut. Res.* **30**, 90050 (2023).
23. L. P. de Rezende, J. Barbosa, and P. Teixeira, *Foods* **11**, (2022).
24. K. Sharma, S. Kothari, N. L. Panwar, and M. R. Patel, *Environ. Sci. Pollut. Res.* **29**, 78887 (2022).
25. S. P. Aubourg, *Antioxidants* **12**, (2023).
26. G. Ghoshal, *Heliyon* **9**, e17532 (2023).
27. H. Cong, Q. Wu, Z. Zhang, and J. Kan, *Front. Nutr.* **10**, 1 (2023).
28. N. E. Rahmani-Manglano, E. M. Guadix, C. Jacobsen, and P. J. García-Moreno, *Antioxidants* **12**, (2023).
29. H. Wu, M. P. Richards, and I. Undeland, *Compr. Rev. Food Sci. Food Saf.* **21**, 1275 (2022).
30. D. Krishnaiah, A. Bono, R. Sarbatly, R. Nithyanandam, and S. M. Anisuzzaman, *J. King Saud Univ. - Eng. Sci.* **27**, 26 (2015).
31. N. Nikmaram and K. A. Rosentrater, *Front. Nutr.* **6**, 1 (2019).
32. C. Lin, Y. Huang, J. Ciou, C. Cheng, G. Wang, and C. You, *Large-Scale Production of Umami-Rich Seasoning Material*, (2023).
33. Y. Zou et al., *Front. Mar. Sci.* **10**, 1 (2023).
34. A. K. Wani et al., *Environ. Sci. Pollut. Res.* **31**, 38960 (2024).
35. S. Borges et al., *Molecules* **28**, 1 (2023).
36. W. Xu et al., *Foods* **11**, (2022).
37. F. Joudi-Sarighayeh, Y. Abbaspour-Gilandeh, M. Kaveh, and J. L. Hernández-Hernández, *Agronomy* **12**, (2022).

38. A. Adrover, C. Venditti, and A. Brasiello, *Foods* **9**, 1 (2020).
39. A. Mahmoud, P. Arlabosse, and A. Fernandez, *Biomass and Bioenergy* **35**, 288 (2011).
40. F. Brahmi et al., *Antioxidants* **12**, (2023).
41. D. Marín-Peñalver, A. Alemán, M. P. Montero, and M. C. Gómez-Guillén, *Food Funct.* **12**, 2137 (2021).
42. G. Chegini, A. HamidiSepehr, M. F. Dizaji, and S. V. Mirnezami, *Int. J. Recycl. Org. Waste Agric.* **3**, (2014).
43. N. Kian-Pour, *Foods* **12**, (2023).
44. R. Zhang et al., *Foods* **12**, (2023).