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RESEARCH ARTICLE

Drying Behavior of Yellowfin Tuna (*Thunnus albacares B.*) Skin as Affected by Different Airflow Rates

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Abstract

The general objective of this study was to determine the drying behavior of yellowfin tuna (*Thunnus albacares*) skin as benchmark research for processing tuna skin as food material. The drying temperature of 47±3°C and airflow rates of 0.95m/s and 0.80m/s were used. The target moisture content of 10.00% w.b. for the final product was attained from an initial moisture content of 61.86% w.b. Result shows that the drying rate was initially faster for 0.95m/s air velocity than at 0.80m/s. At 1.50hrs, case-hardening was observed for 0.95m/s so that drying became slower. Consequently, reaching the final moisture content took a longer time at 0.95m/s. This lead to significant differences in both drying time and drying rate, with better drying characteristics at a slower airflow rate of 0.80m/s. The findings of the study can be used to design a more energy-efficient system of processing tuna skin at mild drying conditions.

Keywords: *drying, drying behavior, drying model, tuna skin, dried tuna skin*

Tuna is one of the important fish species used as processed seafood. It is a species of oily fish belonging to the mackerel family. It is a good source of essential omega-3 fatty acid, vitamin D, and protein, making it a good food for building muscle, promoting skin and hair health, energy metabolism, and booster for the cardiovascular and nervous systems. Hence, tuna has a good nutritional profile with important health benefits [1, 2].

The Philippines is one of the world's largest tuna producers. Twenty percent of its marine fisheries production is contributed by tuna. Yellowfin tuna, which accounts for 25% of the total catch, is the second major species caught in the country next to skipjack. Tuna is marketed fresh, chilled, frozen, smoked, and canned. Tuna processing industries generate several by-products like head, fins, scrape meat and trimmings [3].

On the downside, wastes from the processing of marine animals are obviously major component of coastal wastes [4]. Fish processing industries worldwide discard many million tons of fish waste per year. At least 50% of the material remaining from fish is not utilized as food which leads to almost 32 million tons of waste [5]. Moreover, fishery wastes and by-products can lead to significant management and environmental problems. In several countries, there is an urgent call to explore the possibility of using discards from fishing, aquaculture and traditional fishing instead of facing the challenge of their disposal [6].

About 30% of the by-products derived from the fish processing industry are fish skin, scales, and bones [7]. Fish waste such as tuna skin, which is conventionally discarded as food, can be effectively utilized and made into various products. Dried fish skin can be used as feed material, leather material, or even a delicious crackling locally known as “chicharon”.

Furthermore, dried tuna skin has a long shelf-life compared to fresh tuna skin. This is because drying reduces water content, enzymatic and many chemical processes that are responsible for fish spoilage. As water content is reduced, microbial activity cannot run at a normal rate, thus reducing the spoilage of fish [8].

Presently, there are limited studies conducted on the drying behavior of tuna skin, particularly the yellowfin species. It is important to understand the engineering properties that are necessary for process design, control systems, and quality assessment for dried products. Drying behavior must be clearly understood as necessary for the optimization, design, and operation of the dryer for large-scale industrial applications. Hence, this study was conducted to investigate the influence of airflow rate on the drying behavior of yellowfin tuna skin.

The results of the study would not only contribute to reducing wastes but the product itself can be a valuable source of income for local food processors. With better control over the temperature and moisture content reduction, the use of mechanical dryer, compared to the typical sun-drying, would be hygienic and safe for food consumption since products would not be exposed to possible contamination from the outside environment.

Materials and Methods

Sample Preparation

Fresh tuna skins were procured from General Santos City Public Market. They were initially sorted and washed thoroughly to remove adhering dirt and other foreign materials. In preparing samples before drying, the procedures practiced by local crackling producers were followed. Pre-trials were conducted until the desirable pre-treated tuna skin was produced. The procedure involved salting and cooking. Salts induce osmotic dehydration in fish which can help in partial removal of water [9], as well as develop sensory characteristics. Moreover, cooking is also recommended as a pretreatment method to avoid casehardening which may retard the drying process and decrease the water holding capacity of the product [10]. In this study, the cleaned tuna skin was soaked in brine solution for 3-5 minutes. For every one (1) kilogram of tuna skin, six teaspoon of salt and twelve cups of water were used. The brined tuna skins were then cooked in boiling water for 10-15 minutes. The cooked skins were carefully drained for 3-5 minutes prior to drying.

Drying Equipment and Settings

A pre-fabricated vertical-type mechanical dryer was used to dry the cooked tuna skin. The dryer has six main components, namely centrifugal fan or blower, heating element, thermal control unit, plenum, drying chamber, and exhaust.

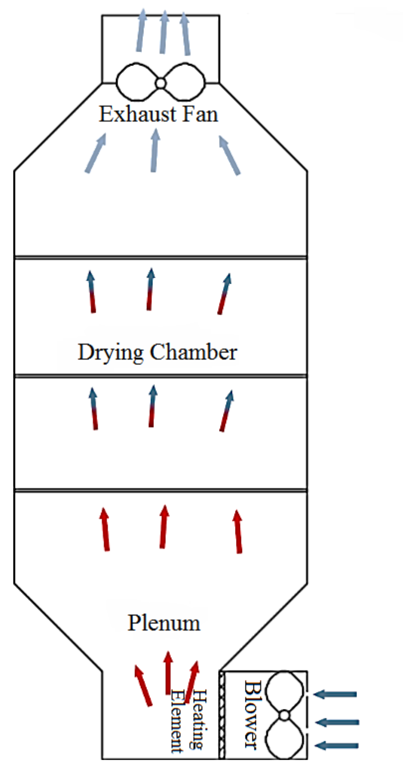

Figure 1. Schematic diagram of the vertical-type mechanical dryer.

The dryer utilizes force convection to heat ambient air as it passes through the heating element. The heated drying air then moves to the plenum to stabilize air pressure and reduce air velocity before it enters the drying chamber. Inside the drying chamber, the tuna skins are laid out in trays arranged vertically in the drying chamber. The difference in temperature and moisture content between the air and the commodity to be dried allows heat and moisture transfer to take place. Air carrying the moisture is then forced out of the chamber with an exhaust fan located in the topmost portion of the dryer.

Due to the limitations of the pre-fabricated dryer, a drying temperature of 47±3.0°C was used. It was achieved by adjusting the thermostat of the heating element. This setting was within the range suitable for drying tropical fish with no signs of heat damage [11]. Low-temperature drying was also found to produce better quality attributes for many fishery products like tuna loins [12], pangasius [13], yellow croaker [14], shark fillets [15] and some species of carp and anchovy [16].

The airflow rates were obtained by adjusting the damper opening of the blower. Full opening with airflow rate at 0.95m/s and half-opening with airflow rate at 0.80m/s settings were used in the study. The half-open damper was the minimum airflow setting that could induce significant changes to the bulk of the products placed inside the dryer. An anemometer was used to determine the velocity of air generated by the blower. Pre-trials were conducted prior to data gathering.

Drying Procedure

Before drying, the samples were cut into uniform sizes of about 1.5-in by 1.5-in having a thickness of approximately 1/8-in and an average weight of 0.40 grams. Samples were arranged in single layer on trays measuring 1.8-ft by 1.8-ft which were then placed in the mechanical dryer. Initial and subsequent weights of samples during drying were measured regularly: every ten minutes for the first 30 minutes, every 15 minutes for the next one hour, every 20 minutes after two hours, and every 30 minutes thereafter until the final moisture content of 10.00%w.b was reached. This moisture content was based on the upper limit for producing crispy products [17] and within the acceptable range for drying various fish products [18, 19]. The moisture content of 10.00% w.b was the target moisture content for producing the final dried tuna skin products.

In other trials, the samples were further dried until the equilibrium moisture content (EMC) was reached. Equilibrium moisture content is a function of the temperature, relative humidity and the product. This does not mean that the material and the air have the same moisture content. It only means that an equilibrium condition exists in such a way that there is no net exchange of moisture between air and the material [20]. In this study, separate trials were conducted for determining the EMC of tuna skin. Samples were subjected to the respective temperature and airflow rates and weighed at regular intervals of time until there was no more change in weight. At this condition, the samples had reached EMC. Values for EMC were used in generating various drying models.

Ambient wet bulb and dry bulb, dryer inlet, and dryer exhaust temperatures were also regularly measured using digital thermometers and psychrometers.

Moisture Content Determination

The initial moisture content wet basis of samples was determined using the oven method for meat as described by AOAC Method 950.46(B). Modifications of the method were done since the oven dryer used does not rely on mechanical convection but only on still air. This method can produce accurate and precise results for a wide variety of products [21]. Samples measuring at least 10 grams were placed into the oven for 48 hours at 105°C. The initial moisture content wet basis was obtained using the equation:

$$MC_O = \frac{W_1 - W_2}{W_1} \qquad \text{equation (1)}$$

where:

MC_O = initial moisture content wet basis of sample before mechanical drying, %
W_1 = initial weight of the sample before oven drying, kg
W_2 = final weight of the sample after oven drying, kg

The instantaneous moisture content of samples was determined using the moisture balance equation expressed as:

$$W_1\,(1\text{-}MC_1) = W_2\,(1\text{-}MC_2) \qquad \text{equation (2)}$$

where:

MC_1 = moisture content of sample before time t, %
W_1 = initial weight of the sample before time t, kg
MC_2 = moisture content of the sample at any time t, %
W_2 = final weight of the sample at any time t, kg

Drying Models

Mathematical models were used to evaluate the effects of airflow rates on drying time. These were the Newton model, Page model, and Henderson and Pabis model of drying which are the most known and fundamental models in agricultural drying used to describe the behavior of mass transfer during drying. These models are derived from Fick's Law and the mechanism of moisture movement is controlled by the diffusion phenomenon [22]. Furthermore, correlation values were used to determine which of the models best fit the data.

Newton Model

$$MR = \exp(-kt) \qquad \text{equation (3)}$$

Page Model

$$MR = \exp(-kt^n) \qquad \text{equation (4)}$$

Henderson and Pabis Model

$$MR = a \exp(-kt) \qquad \text{equation (5)}$$

where:

$$MR = \frac{MC_t - MC_{eq}}{MC_O - MC_{eq}}$$

MR = moisture ratio, dimensionless
MC_t = moisture content at any time t, %
MC_o = initial moisture content, %
MC_{eq} = equilibrium moisture content, %
t = drying time, hr
k, n, a = drying constants

Drying Characteristics Evaluation

The actual drying time of samples was calculated using the equation of the line with the most fitted drying model determined through correlation. For the drying rate, the following formula was used:

$$D_r = \frac{MC_o - MC_f}{t_a} \qquad \text{equation (6)}$$

where:

D_r = drying rate, %MC/hr
MC_O = initial moisture content of the sample, %
MC_f = final and target moisture content of the sample (10.00%)
t_a = actual drying time, hr

Statistical Analysis

A 2x6 single-factor experiment in a completely randomized design (CRD) was used in determining the drying behavior of dried tuna skin with airflow as the factor. To ensure uniformity and homogeneity, tuna skins were prepared in a single batch per trial and trays were interchanged from time to time upon the measurement of weight. In addition, three subsamples were measured in each replication. All data were analyzed using Analysis of Variance (ANOVA) at 5% level of significance with Least Significant Difference (LSD) for the post-hoc tests. Microsoft Excel and SPSS 17.0 were used to perform regression analysis of models, as well as the determination of constants. The same software programs were also used in performing ANOVA and subsequent post-hoc test.

Results and Discussion

Drying Curve

The fresh tuna skin used had an average initial moisture content of 61.86% w.b. Samples were dried until equilibrium moisture contents of 7.95% w.b and 5.91% w.b at airflow rates of 0.95m/s and 0.80m/s, respectively were attained. The drying curves of the product as affected by airflow rates until it reached its equilibrium moisture content are shown in Figure 2.

In the first one hour of the drying process for both airflow rates, there was a rapid and constant removal of moisture content from the tuna skin which is illustrated by the straight-line portions on the graphs. This initial stage in drying is called the constant-rate period. Drying happens through evaporation of surface water to the air stream [23] and it continues as long as the rate of diffusion of free water to the product surface exceeds the evaporation rate [24]. At this stage, moisture removal was faster at the airflow rate of 0.95m/s than at 0.80m/s. This is evident in Figure 2 as the curve for the higher airflow rate lies lower than the lower airflow rate.

Drying of the yellowfin tuna skin slowed down as the process entered the falling-rate period at roughly 1.5 hours. During this period, moisture is not readily available on the surface. Evaporation rate of free water exceeds the rate of moisture diffusion from inside the product to the surface and hence, the drying rate steadily falls [25]. It is also at this point where the curves of the two airflow rates intersected. This means that drying at 0.95m/s slowed down much faster than at 0.80m/s at 1.50 hours. This implies that there is more resistance to moisture diffusion at higher air velocity than at lower air velocity at that time. This phenomenon could be attributed to case-hardening at the beginning of the falling-rate period for the 0.95m/s.

Case-hardening happens at high drying rates where the surface dries out faster than the core [26]. It is dependent on every external factor that increases the initial drying rate [27] and, in this case, the airflow rate. When case-hardening is dominant, moisture removal slows down due to internal resistances for the diffusion of moisture to the surface of the material [28]. As a result, a hard crust is formed on the surface while the water content at the center remains quite high. Case hardening is acute and common in the field of meat drying [29].

The target moisture content of 10.00% w.b. was attained at approximately 3hrs for 0.95m/s and at 2hrs for 0.80m/s. Similarly, equilibrium moisture content (EMC) was reached much faster at lower airflow rate than at lower airflow rate, specifically 3hrs at 0.80m/s and 5hrs at 0.95m/s. This is evident in Figure 2 as the curve for 0.95m/s airflow rate is less steep than for 0.80m/s after 1.5hrs.

Drying Model

Drying models were used to describe the relationship between drying time and product moisture content. Coefficients of determination (R^2) for the different models are shown in Table 1. Linear models are depicted in Figure 3.

There is no definite rule for the fitting of drying models as to which is suitable for drying kinetics of food samples. However, better fitness of drying curves based on moisture and time data is indicated by higher values of R^2, lower values of RMSE and X^2 [30]. In a study conducted by Montazer-Rahmati and Horri [30], drying models with R^2 values of 0.92-0.955 were described as having no very good consistency, those with R^2

Table 1. Coefficient of determination (R^2) of drying models for yellowfin tuna skin as affected by airflow rates.

Airflow Rate (m/s)	Newton	Page	Henderson and Pabis
0.80	0.9228	0.9850	0.9554
0.95	0.9725	0.9926	0.9820

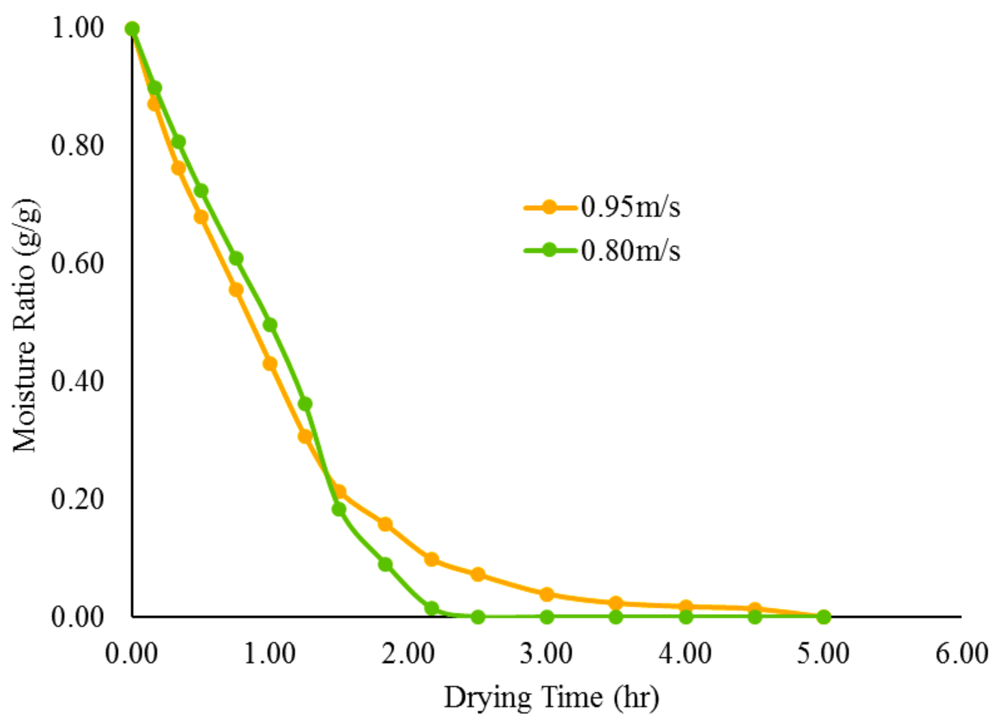

Figure 2. Drying time–moisture ratio relationship for mechanically–dried yellowfin tuna skin as affected by airflow rate.

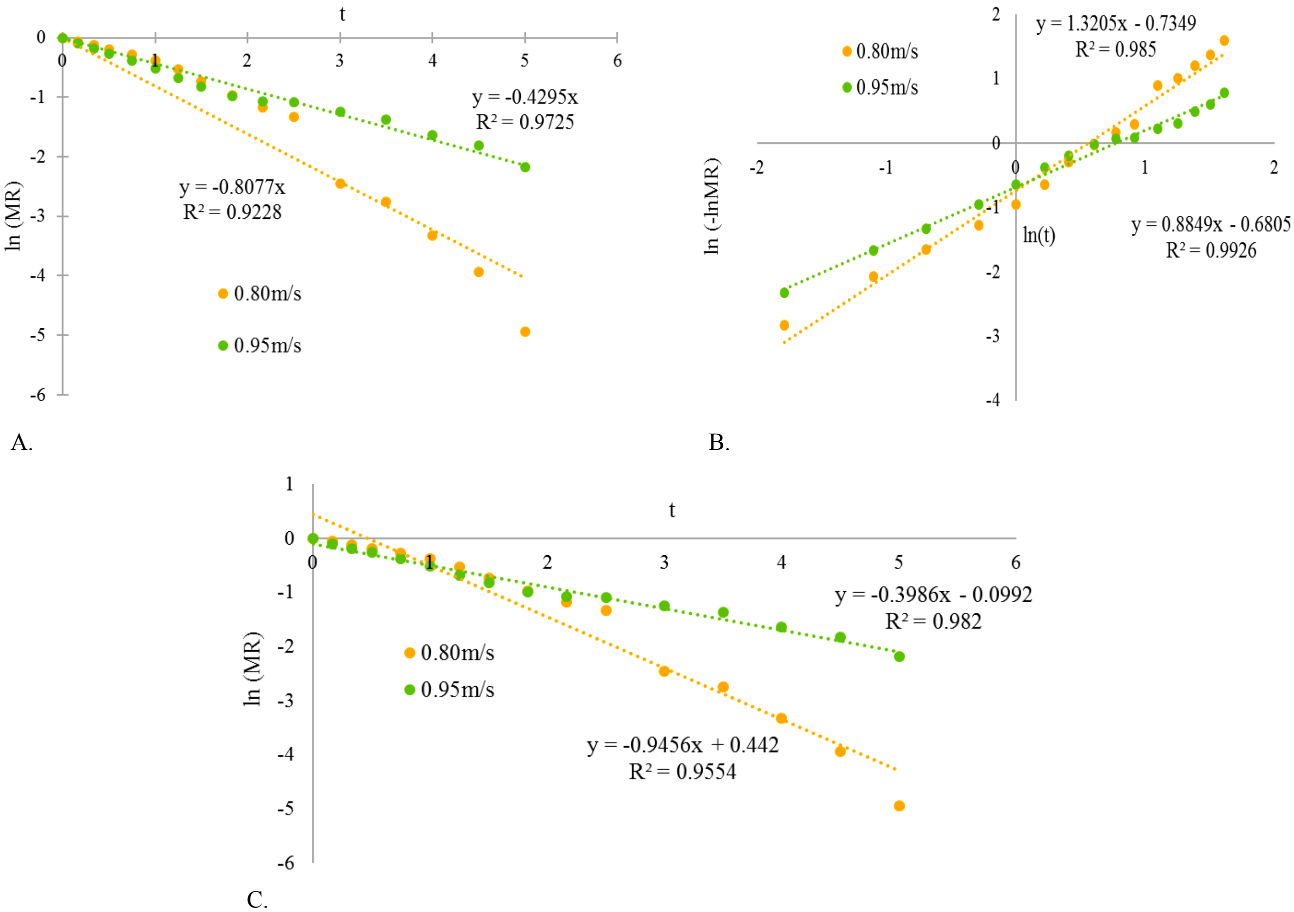

Figure 3. Drying models for mechanically-dried yellowfin tuna skin as affected by airflow rate: (A) Newton model, (B) Page model, and (C) Henderson and Pabis model.

equal to 0.975-0.995 were described as a good fit, and those with R^2 value greater than 0.999 were the best fit. The values of R^2 for the three drying models were high, implying that the drying time has a high correlation with moisture content. Among the three models, the Page model generated the highest R^2 for both airflow rates tested, with values of 0.9850 for 0.80m/s airflow and 0.9926 for 0.95m/s airflow. Hence, the Page model was the best fit for the data. In many literatures, Page model also gave better and more satisfactory predictions for pistachio nuts [31], mango slices [32], semi-refined carrageenan [33], African catfish [34], and beef slices [35] using varied drying techniques. For other studies on drying meat products like pork [36], tilapia fillet [37], and beef [38], Arrhenius-type equation had been developed upon which Fick's Law and diffusion models are based [39].

Drying Characteristics

Table 2 shows the different drying properties of yellowfin tuna skin using varying airflow rates. The exact drying time for the product to reach the desired moisture content of 10.00% w.b was computed based on Page model. The lower airflow rate of 0.80m/s resulted to a shorter drying time of 3.72hrs in comparison to 0.95m/s at 6.03hrs drying time.

From the drying curve (Figure 2), the higher airflow rate had faster moisture removal until 1.5hrs when it slowed down and was overtaken by the lower airflow rate. It was also at this point that the product entered the falling-rate period when the evaporation of surface moisture decreased and diffusion of moisture from the interior of the product became more dominant. Hence, increasing the air velocity can only increase mass transfer at the surface, thereby increasing the drying rate for as long as surface evaporation is the controlling mechanism [40]. When there is limited free water and drying become predominantly through diffusion, higher air velocities becomes ineffective. Air velocity has no direct influence on the internal water transport and thus, it should not significantly affect the drying rate at the falling rate

Table 2. Drying parameters for yellowfin tuna skin as affected by airflow rates using vertical-type mechanical drying.

Airflow Rate (m/s)	[1]Mean Drying Time (hr)	[2]Mean Drying Rate (%MC/hr)
0.80	3.72[a]	14.21[a]
0.95	6.03[b]	8.71[b]

Notes: Values with different letters are significantly different at 5% level of significance.
ns means not significantly different at 5% level
[1]CV = 13.81%, [2]CV = 16.49%, [3]CV = 29.6%

period [28]. Case-hardening could have also happened at 1.5hrs because more internal resistance to moisture movement was observed.

The drying time – drying rate relationship of different treatment combination is shown in Figure 4. In the first twenty minutes of drying, the tuna skin experienced an induction period where surface temperature adjusts to the drying air temperature and thus, the heat of evaporation equals the convective heat due to temperature gradient [41]. This can be seen as irregularity in the first two or three points of the curves for both airflow rates. After this, the drying of the product entered the constant-rate period until 1.5hrs. This can be seen as the nearly equal drying rates (28.20-31.85% MC/hr) or nearly horizontal lines in Figure 4. After 1.5hrs, drying entered the falling-rate period where the drying rate gradually decreases, or the moisture removal becomes slow since more energy is required to break the molecular bond of the moisture [42]. This is seen as falling curves beyond 1.5hrs in the graphs for both airflow rates. However, the curve drops faster for 0.80m/s and the product attained the final moisture quickly. For 0.90m/s, there were fluctuations in the falling rate period possibly because of case-hardening which limits moisture diffusion. Fluctuations in the critical moisture contents where drying enters another period have been widely observed in many materials [43, 26].

Figure 5 further confirms the observations discussed. At high moisture content or the beginning of the drying process, the curve for 0.95m/s is situated higher than for 0.80m/s. This means that drying was faster for the higher airflow rate. At roughly 25.00% moisture content w.b (or roughly MR=0.30 at 1.50hrs in Figure 2), the two curves intersected. It was at this point that

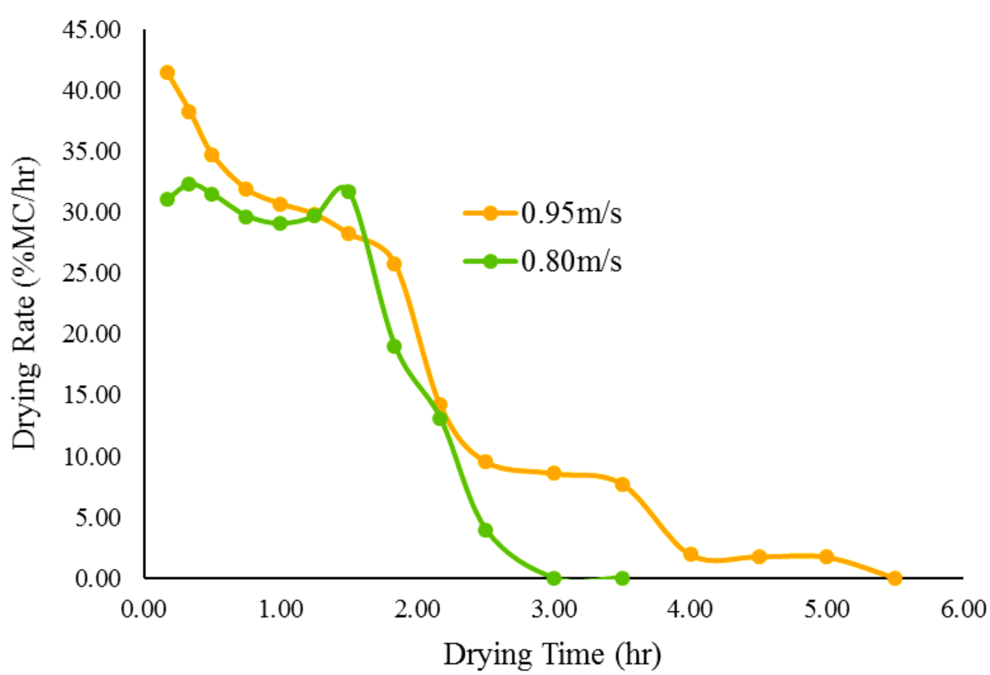

Figure 4. Drying time – drying rate relationship for mechanically-dried yellowfin tuna skin as affected by airflow rate.

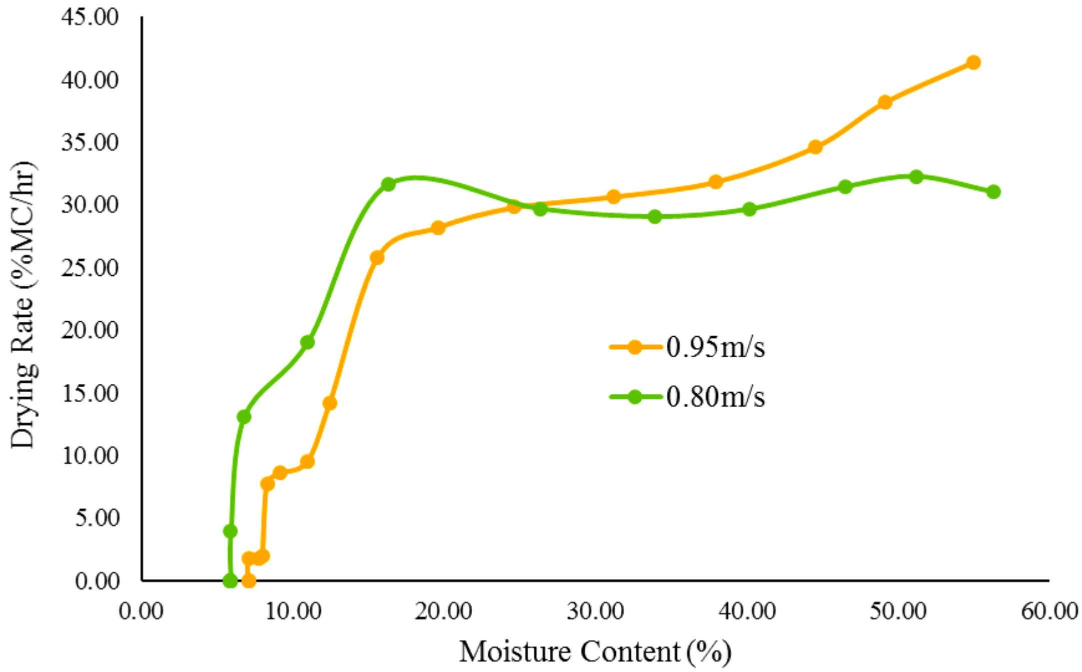

Figure 5. Moisture content–drying rate relationship for mechanically–dried yellowfin tuna skin as affected by airflow rate.

case-hardening occurred where drying rate was slower for 0.95m/s than at 0.80m/s.

The phenomenon resulted to faster mean drying rate of 14.21%MC/hr for 0.80m/s, compared to 0.95m/s at only 8.71%MC/hr (Figure 5). Statistically, the drying time and drying rate for the two airflow were significantly different. Thus, the lower airflow rate of 0.80m/s was able to dry tuna skin at a much faster pace.

Conclusion

This study was conducted to determine the drying behavior of yellowfin tuna skin as influenced by varying airflow rates. An average temperature of 47±3°C and airflow rates of 0.95m/s and 0.80m/s were used.

From an average initial moisture content of 61.86% w.b, the tuna skin was dried until the target moisture content of 10.00%w.b was reached to produce the desired final products, and up to equilibrium moisture content in order to create the drying models. From the three models created, the Page model was found to be the best-fitted model for the data. The model was then used to estimate the exact drying time, drying rate, and other parameters.

Of the two airflow rates, longer drying time (6.03hrs) was observed for 0.95m/s, consequently leading to a slower drying rate of 8.71% MC/hr. This was attributed to the case-hardening phenomenon that happened to the dried product. At the drying time of 3.73hrs and drying rate of 14.21% MC/hr, the lower airflow rate of 0.80m/s showed promising results that were significantly different from the higher airflow.

In general, the study showed that the lower airflow rate resulted in shorter drying time and faster drying rate.

As this study serves as benchmark research, it is recommended that further experiments be conducted to validate discussions and thus, provide more meaningful results and applications, particularly to the food industry. First one, such experiment must explore the effects of other drying parameters, i.e. air temperature and relative humidity, in the drying behavior of tuna skin. The influence of drying temperature may further solidify observations of case-hardening of products even at low airflow rate. Another experiment must verify the effects of airflow rates on the equilibrium moisture content of the product since there are limited literatures on the airflow-EMC relationship. Also, only one tray must be utilized to hold products while being dried in order to prevent random errors caused by the variability of drying conditions inside the dryer. Furthermore, it is advised that computations be made of sensory qualities of the cracklings or chicharon made from dried tuna to the commercially available cracklings to assess product acceptability and saleability. Lastly, the team recommends the conduct of further laboratory testing, i.e. proximate analysis, rheology, to provide more concrete scientific support to the observations.

Acknowledgment

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References

[1] Bell, J.D., Allain, V., Allison, E.H., Adrefouet, S., Andrew, N.L., Batty, M.J., Blanc, M., Dambacher, J.M., Hampton, J., Hanich, Q., Harley, S., Lorrain, A., McCoy, M., McTurk, N., Nicol, S., Pilling, G., Point, D., Sharp, M.K., & Williams, P. (2015). Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. *Marine Policy*, 51, 584-591.

[2] Garaffo, M.A., Vasallo-Agius, R., Nengas, Y., Lembo, E., Rando, R., Maisano, R., Dugo, G., & Giuffrida, D. (2011). Fatty acids profile, atherogenic (IA) and thrombogenic (IT) health lipid indices, of raw roe of blue fin tuna (*Thunnus Thynnus* L.) & their salted product "bottarga". *Food and Nutrition Sciences,* 2, 736-743.

[3] Guerrero, R.D. (2018). Updates on our tuna industry. In: *Agriculture Monthly*. Retrieved from: https://www.agriculture.com.ph/2018/04/10.00/updates-on-our-tuna-industry/

[4] Sayana, K.S. & Sirajudheen, T.K. (2017). By-products from Tuna processing wastes – an economic approach to coastal waste management. *Proceedings of the International Seminar of Coastal Biodiversity Assessment*, 411-420.

[5] Kristinsson, H.G. & Rasco, B.A. (2000). Fish protein hydrolysates: production, biochemical, and functional properties. *Critical Reviews in Food Science and Nutrition,* 40, 43-81.

[6] Caruso, G. (2015). Fishery wastes and by-products: a resources to be valorized. *Journal of Fisheries Sciences*, 9(4), 80-83.

[7] Wasswa, J.B. & Tang, J. (2015). Utilization of fish processing by-products in the gelatin industry. *Food Reviews International,* 23(2), 159-174.

[8] Ghaly, A.E., Budge, D.S., & Brooks, M.S. (2010.00). Fish spoilage mechanisms and preservation techniques: review. *American Journal of Applied Sciences*, 7(7), 859-877.

[9] Oladele, A.K. & Odedeji, J.O. (2008). Osmotic dehydration of catfish (*Hemisynodontis membranaceus)*: effect of temperature and time. *Pakistan Journal of Nutrition,* 7(1), 57-61.

[10] Rahman, Mohammad. (2006) Drying of Fish and Seafood. doi:10.00.1201/9781420017618

[11] International Labour Office, United Nations (1982). Salting-drying-fermenting. In: Small-Scale Processing of Fish, 140 pp.

[12] Esteves, E. & Anibal, J. (2018). Optimization of processing conditions of traditional cured tuna loins – muxama. *Fishes*, 3(3), 1-12.

[13] Kumar, G.P., Martin Xavier, K.A., Nayak, B.B., Kumar, H.S., Venkateshwarlu, G., & Balange, A. (2017). Effect of different drying methods on the quality characteristics of *Pangasius hypophthalmus*. *International Journal of Current Microbiology and Applied Sciences,* 6(10.00), 184-195.

[14] Kim, B., Oh, B., Lee, J., Yoon, Y.S., & Lee, H. (2020). Effects of various drying methods on physicochemical characteristics and textural features of yellow croaker (*Larimichthys polyactic*). *Foods,* 9(196), 1-11.

[15] Mujaffar, S. & Sankat, C.K. (2011). The effect of temperature on the drying characteristics of salted shark fillets. *The West Indian Journal of Engineering*, 33, 19-25.

[16] Oduor-Odote, P.M., Shitanda, D., Obiero, M., & Kituu, G. (2010.00). Drying characteristics and some quality attributes of *Rastrineobol argantea*

(omena) and *Stolephorus delicatulus* (kimarawali). *African Journal of Food Agriculture,* 10.00(8), 2998-3014.

[17] Hecke, E.V., Allaf, K., & Bouvier, J.M. (2007). Texture and structure of crispy-puffed food products part II: mechanical properties in puncture. *Journal of Texture Studies*, 29(6), 617-632.

[18] Daramola, J.A., Fasakin, E.A., & Adeparusi, E.O. (2007). Changes in physicochemical and sensory characteristics of smoke-dried fish species stored at ambient temperature. *African Journal of Food, Agriculture, Nutrition and Development*, 7 (6), 1-16.

[19] Bala, B.K. & Mondol, R.A. (2006). Experimental investigation on solar drying of fish using solar tunnel dryer. *Drying Technology,* 19(2).

[20] Wilhelm, L.R., Suter, D.A., & Brusewitz, G.H. (2004). Drying and dehydration. In: *Food & Process Engineering Technology,* 259-284.

[21] Leffler, T.P., Moser, C.R., McManus, B.J., Urh, J.J., Keeton, J.T. & Claflin, A. (2008). Determination of moisture and fat in meats by microwave and nuclear magnetic resonance analysis: Collaborative study. *Journal of AOAC INTERNATIONAL,* 91(4), 802-810.00.

[22] Jayas, D.S., Cenkowski, S., Pabis, S. & Nuir, W.E. (1991). Review of thin-layer drying and wetting equations. *Drying Technology,* 9(3), 551-588.

[23] Velic, D., Planinic, M., Tomas, S. & Bilic, M. (2004). Influence of airflow velocity on kinetics of convection apple drying. *Journal of Food Engineering,* 64(1), 97-10.002.

[24] Richardson, J.F. & Backhurst, J.R. (2002). Drying. In: *Chemical Engineering* (Fifth Edition), Volume 2, Elsevier Ltd.

[25] Gulati, T. & Datta, A.K. (2015). Mechanistic understanding of case-hardening and texture development during drying of food materials. *Journal of Food Engineering,* 166, 119-138.

[26] Berk, Z. (2009). Dehydration. In: *Food Process Engineering and Technology. Elsevier Inc.,* 459-510.

[27] Katekawa, M.E. & Silva, M.A. (2007). Drying rates in shrinking medium: Case study of banana. *Brazilian Journal of Chemical Engineering,* 24(4), 1678-1686.

[28] Shank, J.L. (1982). Drying meat. *United States Patent Office Ser. No. 112,760,* 99-208.

[29] Gamli, Ömer. (2014). *A Review Based on the Relationship Among Drying, Curve Fitting and Mathematical Models in Food Systems*. 1. 47-53.

[30] Montazer-Rahmati, M. & Horri, Bahman. (2005). From Laboratory Experiments to Design of a Conveyor-Belt Dryer via Mathematical Modeling. *Drying Technology. 23.* 2389-2420. doi: 10.1080/07373930500340460.

[31] Kashaninejad, M., Mortazavi, A., Safekordi, A. & Tabil, L.G. (2007). Thin-layer drying characteristics and modeling of pistachio nuts. *Journal of Food Engineering,* 78(1), 98-108.

[32] Pu, Y. & Sun, D. (2015). Vis-NIR hyperspectral imaging in visualizing moisture distribution of mango slices during microwave-vacuum drying. *Food Chemistry,* 188 (1), 271-278.

[33] Pantuhan, G.P., Elepaño, A.R., Yaptenco, K.F. & Carpio, E.V. (2017). Mass transfer kinetics during osmotic dehydration of semi-refined carrageenan. *International Journal of Multidisciplinary Approach and Studies,* 4(6), 89-98.

[34] Sobukola, O.P. & Olatunde, S.O. (2011). Effect of salting techniques on salt uptake and drying kinetics of African catfish (*Clarias gariepinus*). *Food and Bioproducts Processing*, 89 (3), 170-177.

[35] Aykin-Dincer, E. & Erbas, M. (2018). Drying kinetics, adsorption isotherms and quality characteristics of vacuum-dried beef slices with different salt contents. *Meat Science,* 145, 114-120.

[36] Clemente, G., Bon, J., Sanjuan, N., & Mulet, A. (2011). Drying modelling of defrosted meat under forced convection conditions. *Meat Science,* 88(3), 374-378.

[37] Guan, Z., Wang, X., Li, M. & Jiang, X. (2013). Mathematical modeling on hot air drying of

thin layer fresh tilapia fillets. *Polish Journal of Food and Nutrition Sciences,* 63(1), 25-34.

[38] Trujillo, F.J., Wiangkaew C., & Tuan Pham, Q. (2007). Drying modelling and water diffusivity in beef meat. *Journal of Food Engineering*, 78(1), 74-85.

[39] Goswami, T.K. & Mangaraj, S. (2001). Advances in polymeric materials for modified atmosphere packaging (MAP). *Multifunctional and Nanoreinforced Polymers for Food Packaging*, 163-242.

[40] Putra, R.N. & Ajiwiguna, T.A. (2017). Influence of air temperature and velocity for drying process. *Engineering Physics International Conference, EPIC 2016,* 170, 516-519.

[41] Chinenye, N.M., Ogunlowo, A.S. & Olukunle, O.J. (2010.00). Cocoa bean (*Theobroma cacao* L.) drying kinetics. *Chilean Journal of Agricultural Research*, 70(4), 633-639.

[42] Amador, C. & de Juan, L.M. (2016). Modeling of particle structure during drying. *Computer Aided Chemical Engineering*, 39, 509-579.

[43] Neikov, O.D. (2019). Processing of powders and processing equipment. *Handbook of non-ferrous metal powders,* 2nd ed., Elsevier Ltd.