

A photograph of a whole fish, likely a sea bream, resting on a wooden cutting board. The fish is positioned horizontally, facing left. To its right are several thin, white onion rings. Above the fish are several slices of bright yellow lemons. The cutting board is set on a dark, speckled surface. The entire image is framed with rounded corners.

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Full Length Research Paper

Moisture sorption isotherm of Tuna Se'i, smoked with liquid smoke

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One of the meat products in East Nusa Tenggara is called "se'i", commonly made from beef, pork, deer meat, and recently have been developed using fish meat. Moisture Sorption Isotherm (MSI) is an important characteristic of food which is almost affected to aspect of the dehydration process and storage stability of the dried product. The aims of this study are to produce tuna se'i using liquid smoke with different concentrations, and to determine the MSIs using a constant relative humidity chamber. In this method, water content of samples are allowed to equilibrate in a closed chamber with a salt solution which produces a desired relative humidity. Tuna se'i were made from two part of the tuna meat, that is, dorsal and belly. Five liquid smoke concentrations were used to dip the meats, that is, 1.0, 1.2, 1.4, 1.6 and 1.8%. The results show higher water content in se'i from dorsal and the lower in se'i made from belly. The equilibrium moisture contents for samples in lower RHs (< 54%) ranged between 2.65 and 12.79% dry basis (db), while in higher relative humidities (RHs) (>54%) ranged between 11.12 and 75.65% (db). Using five models equations, Oswin models shown best fit values of regression coefficients, with ranges value of relative determination, 4.81 to 9.89, and MSI curves were sigmoid. From the MSI curves, can be conclude that tuna se'i need a packaging for storage in ambient temperature specially RHs above 50%.

Key words: Liquid smoke, se'i, moisture sorption isotherm (MSI), equilibrium moisture content.

INTRODUCTION

Every region in Indonesia has a typical food preferred, in accordance with raw materials and additional materials are available locally. Se'i meat is one of the popular products processed in East Nusa Tenggara (ENT) especially community those living in mainland of West Timor. Since beginning, se'i are made from beef, buffalo, horse, deer and pork meats but recently, se'i were also processed using fish meat. These products have been

widely introduced, especially through those who have been visited ENT.

Se'i meat were processed by direct smoking using woods fire at temperature of 60 to 100°C for 4 to 12 h, depend on meat size and ultimate water content needed. There are dry product, for long shelf life, and half-dry product for short shelf life or for storage in refrigerator. Se'i obtained by direct smoking usually varied in

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appearance, taste, and chemical composition. In addition, safety of products is still low. A modification of the processing using liquid smoke to dip the fish meat and then dried in cabinet drier, produced a good quality of se'i. The processing is more hygienic, and the product can be standardized (Berhimpon et al., 2014).

As a specific product, Tuna se'i have physical, chemical and microbiological characteristics, that is different from other food. One factor affecting the characteristics is a properties of moisture sorption isotherms (MSI) (Labuza, 1984). Furthermore the general model of the food MSI curve can be used to design a model of handling and the shelf life of raw materials and processed food MSI value could be influenced by the water content and water activity (a_w) of each materials.

The presence of water in food can be classified in two types, that is, free water and bound water. The nature of free water in food is the same as an ordinary water which has a value of $a_w = 1$, while the bound water is closely related to the composition of foodstuffs and have a_w less than 1 (Labuza, 1984; Schmidt, 2007). Bound water contained in foodstuffs consists of three fractions namely primary bound water is also often called a monolayer of water, and secondary bound water, and tertiary bound water (Labuza and Altunakar, 2007), which generally serves as solvent for solid molecules, because it has a hexagonal structure (Soekarto and Adawiyah, 2012).

Foodstuffs in generally can absorb water from the surrounding (adsorption) because of the humidity outside material is higher, or vice versa can remove some of the water into the air (desorption) due to humidity outside material is low. The term sorption according to Van-den Berg and Bruin (1981) is the process by which solid of a food combines with water in a reversible process involving physical adsorption and capillary condensation. The equilibrium moisture content relationship with the activity of water at a certain temperature the sorption isotherm curve depicted on the water. Each food has a typical moisture sorption isotherm curve.

Labuza (1984) explains that there are three forms of MSI curve which is generally used to describe the moisture sorption models experienced by foodstuffs. Furthermore, based on the state of water in foods that characterize a_w of 0.0 to 1.0, then the MSI curve is divided into three parts. The first region with $a_w < 0.3$, second region with $0.3 < a_w < 0.7$ and third regions with $a_w > 0.7$ (Arslan and Togrul, 2005; Labuza and Altunakar, 2007). Five mathematical models have been used in this research to fit the MSI data, that is, Hasley, Chen Clayton, Henderson, Caurie, Oswin.

The aims of this study are to obtain the equilibrium moisture content and mathematical model to fit the MSI of Tuna's se'i.

MATERIALS AND METHODS

This research was conducted at the Fish Handling and Processing

Laboratory, Faculty of Fisheries and Marine Sciences, Sam Ratulangi University, from October to December 2014. Materials used in this study are: Dorsal and belly meat of Tuna; Ingredients: salt, garlic, shallots, galangal, lemon grass, coriander and pepper. Smoking was done using liquid smoke produced by the laboratory (Berhimpon et al., 2014).

Five liquid smoke concentrations were used to dip the meats, that is, 1.0, 1.2, 1.4, 1.6 and 1.8%. Saturated salt solutions used to provide a range of nine types of RH, that is, NaOH, LiCl, MgCl₂, K₂CO₃, Mg(NO₃)₂, NaNO₂, NaCl, KCl and K₂SO₄, provided nine RHs of 6.9, 11, 32, 44, 53, 64, 76, 87 and 97%, respectively (Berhimpon, 1990; Chalermehat and Owasi, 2011; Ansari et al 2011).

The equipments used in processing of se'i namely: Cool box, knives, cutting boards, buckets, trays, glass bowl, and drying cabinets. While the device used for the determination of moisture sorption isotherm is, desiccators, sample bottles, porcelain bowls and analytical balance.

Fresh tuna were taken from Blue Ocean Grace International Company, at *Aer Tembaga Bitung*, Indonesia. Fillet were provided with a size of 12 x 2 x 2 cm and then washed, drained, weighed, and divided into 12 experimental units of 500 g each. The fillets were soaked in the 2% salt solution for 30 min, drained for 20 min. Furthermore was the fillets divided into two groups. The first group soaked in five concentration liquid for 30 min, then drained for 20 min and soaked in spices solution for 2 h, then drained 20 min and dried in a cabinet dryer for 4 h at a temperature of 70 to 80°C. The second group were followed a traditional method, were fillets directly soaked in spice solution for two hours, then drained for 20 min and smoked in smoking cabinet for 4 h at temperature of 70 to 80°C (Meko, 2007).

To determine MSI, sample was crushed and then weighed about 2 g into the sample box. Furthermore, the sample box was put into desiccators with different humidity. Weighing of the samples was done every 48 h until a constant weight was obtained (Rahman et al., 1995). Equilibrium moisture content of samples that have reached constant weight were immediately measured using the oven method (AOAC, 2005).

Water sorption isotherm curve modeling

There are several mathematical models are commonly used in describing the MSI curve models of foodstuffs. In this study, five models used to fit MSI curve was used (Table 1).

Appropriate model were selected by values of mean relative determinant (MRD). Formula (1) were used to calculate MRD:

$$MRD = 100/n \sum_{i=1}^n \left(\frac{M_i - MP_i}{M_i} \right) \quad (1)$$

Where: M_i = Levels of experimental results, MP_i = water content calculation and n = number of data

The value of $MRD < 5$, the MSI models can describe the actual situation, the value of $5 < MRD < 10$, the model describes the state of approaching the truth, and $MRD > 10$, the model cannot describe the actual conditions (Isse et al., 1983; Bajpai et al., 2011).

RESULTS AND DISCUSSION

Water content of Tuna's Se'i

Water content of Tuna's se'i made from dorsal meat is higher than that of Tuna's se'i made from belly meat.

Table 1. Five models used in describing MSI curve of Tuna's Se'i.

Models	Form equation	
	Form linear	Linerization (Y = a + bx)
Hasley ^{ac)}	$\text{Log}(\ln(1/a_w) = \log P(1) - P(2) \text{ Log Me}$	$Y = \text{Log} (\ln (1/a_w); a = \log P(1); b = -P(2)$ $x = \text{Log Me}$
Chen Clayton ^{bc)}	$\text{Ln}(\ln(1-a_w) = \ln P(1) - P(2) \text{ Me}$	$Y = \text{Ln}(\ln(1-a_w); a = \ln P(1); b = -P(2)$ $x = \text{Me}$
Henderson ^{cd)}	$\text{Log} (\ln(1/(1-a_w) = \log K + n \log \text{ Me}$	$Y = \text{Log} (\ln(1/(1-a_w); a = \log K; b = n$ $x = \log \text{ Me}$
Caurie ^{bc)}	$\text{Ln Me} = \text{Ln P}(1) - P(2) a_w$	$Y = \text{Ln Me}; a = \text{Ln P}(1); b = -P(2)$ $x = a_w$
Oswin ^{ac)}	$\text{Ln Me} = \ln P(1) + P(2) (a_w/(1-a_w)$	$Y = \text{Ln Me}; a = \ln P(1); b = P(2)$ $x = (a_w/(1-a_w)$

Source: ^aIsse et al. (1983); ^bChirief and Iglesias (1978), ^cRahayu et al. (2005).

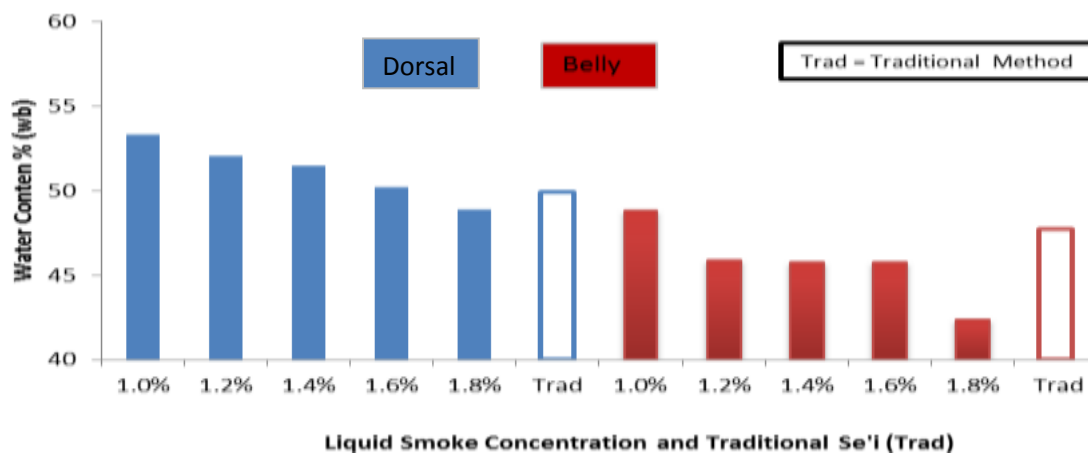


Figure 1. Moisture content of Tuna's se'i with different liquid smoke concentrations and traditional se'i

Concentration of liquid smoke used were not significant ($P > 0.05$) on water content. Differences in water content can be seen in Figure 1. The figure show that the higher concentration of liquid smoke applied in Tuna se'i, the lower the water content. This is because the higher the concentration of liquid smokes the lower the pH. The pH value of liquid smoke decreased with increased liquid smoke concentration, that is, 3.19, 3.13, 3.06, 2.95 and 2.85 for concentration of 1.0, 1.2, 1.4, 1.6, and 1.8 respectively. Low pH affected denaturation of meat and the denaturation can cause a decrease in the ability to hold water during the drying process. Soekarto and Adawiyah (2012) states that the food products or biological materials, have different ability to bind water, depending on the type of chemical compound, the molecular structure, cell shape, pH and humidity of the environment. The water binding ability of meat and products is largely determined by pH's isoelectric (Lawrie et al., 2003; Lonergan and Lonergan, 2005; Elvira, 2007).

In addition to the effect of pH, protein denaturation is also caused by the heat during the drying process in cabinet dryer and smoking. Denaturation has a positive or negative effect on the water content of the meat (Zielbauer et al., 2016).

Tuna se'i produced, had moisture content ranges from 42.36 to 53.29% (wb) can be classified to intermediate food. Winarno (1993) stated that material which has a moisture content in the range of 15 to 50% (wb) is classified as an intermediate food. Meanwhile, according to Taukist and Richardson (2007), intermediate foods has a water content of 10 to 40% (wb) and a_w between 0.60 to 0.90.

Equilibrium moisture content

The equilibrium moisture content (EMC) of Tuna's se'i made using liquid smoke with different concentrations

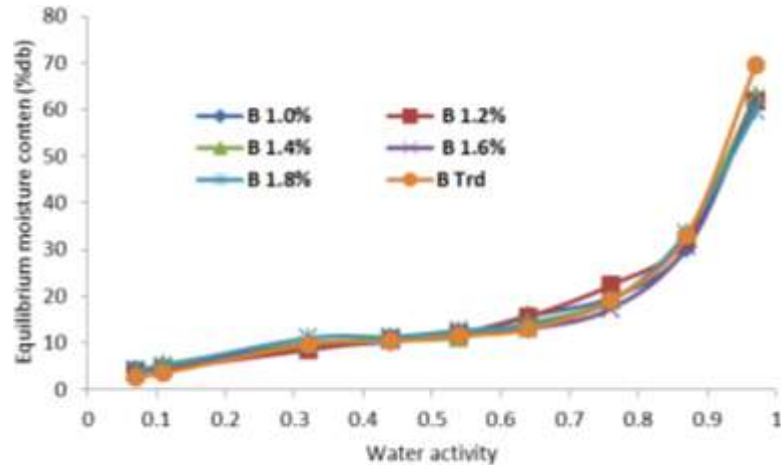


Figure 2. MSI curves of Tuna's se'i made from dorsal meat (D).

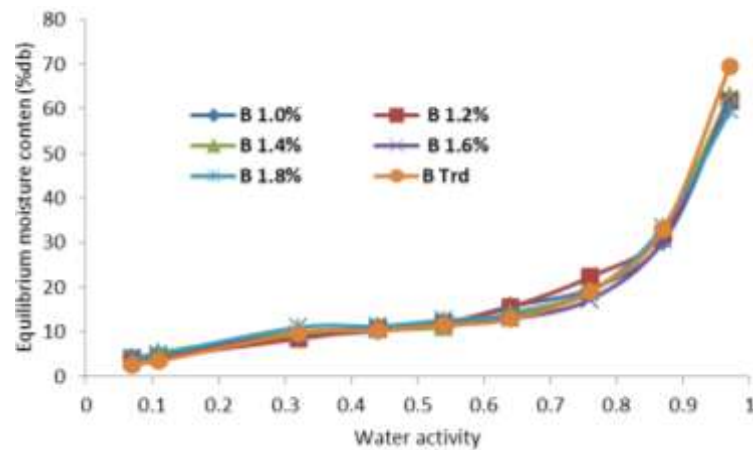


Figure 3. MSI curves of Tuna's se'i made from belly meat (B).

achieved during the 8 to 28 days after stored in RHs range from 7 to 97%. The higher the RHs the longer the EMC reached. Tuna's se'i samples were stored in RHs 7-32, 44-76 and 87-97%, generally reached equilibrium in average at 8-12, 14-20 and 24-28 days, respectively, with EMC average at 3.52-10.04, 11.37-20.29 and 34.09-66.83% (db) respectively.

Labuza and Altunakar (2007) divided food into three groups, that is, monolayer, multy-layer, and free water layer. If EMCs were grouped into the three groups, that is, mono layer (RHs <32%), multilayer (32-76% RHs) and free layer (RHs > 76%), the EMC of dorsal meat were <12.15, 12.15-22.61 and 22.61-75.7% (db) respectively, while the belly meat were <10.97, 10.97- 22.34 and 22.34-69.92% (db) respectively. This shows that the equilibrium moisture content in the dorsal meat are generally slightly higher than that in the belly. The different interval equilibrium moisture content due to the loin is striking at RHs > 76%, because the moist

environment allows the material to absorb more water vapor. Arslan and Togrul (2005) stated that at RHs >76% high humidity environments, allowing the material has a high equilibrium moisture content, because the water is trapped in the capillary spaces. Hysterical curve shape of food containing high protein such as soy, egg white and freeze-dried pork, show similarities with the lop hysterical wide with elevated levels of high water in a_w 0.9 to 1.0 (Labuza and Altunakar, 2007; Catelam et al., 2011).

The relationship between RHs and the equilibrium moisture content describes the characteristic of the MSI. Moisture sorption isotherm of tuna se'i can be seen in Figures 2 and 3. The curves show a sigmoid, generally found in foodstuffs and products. The sigmoid curve is influenced by the accumulation of the combined effects of colligative, capillary and solid surface interaction with water, (Labuza and Altunakar, 2007; Bell and Labuza, 2000). The temperature and the composition of the material, can affect changes in the form of interaction of

Table 2. Values of MRD using five mathematical models.

Treatments		Models				
Loin	Liquid smoke concentration (%)	Hasley	Chen Clayton	Handerson	Caurie	Oswin
Dorsal	1.0	13.99	67.71	23.48	17.29	7.98
	1.2	19.85	67.71	23.46	17.29	8.86
	1.4	16.48	80.29	21.67	20.69	8.25
	1.6	19.81	55.40	24.83	17.84	9.50
	1.8	21.65	50.89	26.68	17.25	9.89
	Traditional method	9.35	72.93	11.96	15.65	9.41
Belly	1.0	8.28	54.26	11.05	12.85	5.33
	1.2	24.03	49.78	58.38	11.44	4.84
	1.4	10.46	60.15	12.26	18.05	9.67
	1.6	10.73	64.89	13.61	18.30	8.91
	1.8	13.54	49.95	15.71	16.07	8.22
	Traditional method	17.21	90.05	20.23	19.39	8.48

water molecules in food (Wydiotomo et al., 2011; Catelam et al., 2011). Iglesias and Chirife, (1976), noted that sorption region is generally influenced by the interaction of water molecules in food.

Both MSI curves of tuna se'i also shows that, in the range of RHs < 76% equilibrium moisture content increased sharply, precisely at 87% RH. Berhimpon (1990) found that MSI of salted dried yellow tail have the same trend. Figures 2 and 3 explained that product will adsorb water when stored in ambient temperature with RHs > 75%, and in this condition packaging of the product is needed. The product been stored in RHs < 75% will be more stable. This indicated that Tuna's se'i at RHs > 87% has a high ability to absorb water from the environment. The interaction of muscle meat with moisture caused increase in tertiary bound waters. Soekarto and Adawiyah (2012) stated that in foodstuffs, organic compounds have a high ability to trap water in capillary. Furthermore they stated that the jelly and grass jelly are able to bind water 10 to 20 times of the dry weight while fresh fish 3 to 4 times, compared to grain is only 1/8 to 1/9 times the weight of the solid.

The accuracy of the models

Equilibrium moisture content were analyzed using the five equations model in Table 1, and the results were shown in Table 2.

Table 2 showed that there are two equation models (Hasley and Oswins models).with MRD value < 10. Hasley models only shown value >MRD 9.35 and 8.28 traditional se'i and se'i made of belly meat dip in 1% liquid smoke. Chirief and Inlesias, (1978) stated that Oswin equation models have a high suitability for predicting MSI on foodstuffs with RHs of 0 to 85%.

Based on the value of MRD in Table 2, Oswin models

was chosen to fit MSI curve because it have a values of MRD tested <10 for all treatments. MSI curve is a relationship between a_w , and the equilibrium moisture content of each treatment (Me_t) and the equilibrium moisture content prediction (Me_p) (Bajpai et al., 2011).

Figure 4 shown that the curve was smoother; the lines have a high accuracy coincidence. The smaller the value of MRD, the more precise the model also describes the phenomenon in which the sorption isotherm occurs in foodstuffs and products (Walpole, 1990; Chalermachit and Owasit, 2011; Ansari et al., 2011). MSI curve smoothness in food is influenced by the form of equations and parameters used. Oswin equation model is a simple model of the five models selected. A simple equation models with few parameters generally provide high curve smoothness (Labuza, 1982). Hadrich et al. (2008) investigated the desorption of Tunisian sardine at temperatures of 25, 35 and 50°C found Oswin equation was the best model to fit the experimental or date, whereas Bajpai (2011) noted that at temperature 10 and 70°C, Gugenheim-Anderson-de Boer (GAB) and Oswin models give reliable results for meat and meat products.

Conclusion

The water content in the Tuna's se'i made from dorsal meat was higher than belly meat. Decrease in water content is caused by an increase in liquid smoke concentration used. Equilibrium moisture content, reached varied between RHs <32, 32, 76 and >76%, that is 8, 12 and 24 days of storage, respectively. The MSI curve tuna se'i was a sigmoid shaped, Equation model that gives rather precise predictions was Oswin equation, with MRD value ranging from 4.81 to 9.67. The level of water absorption of Tuna's se'i rose sharply at RHs >76%, therefore packaging of the product at the high RHs

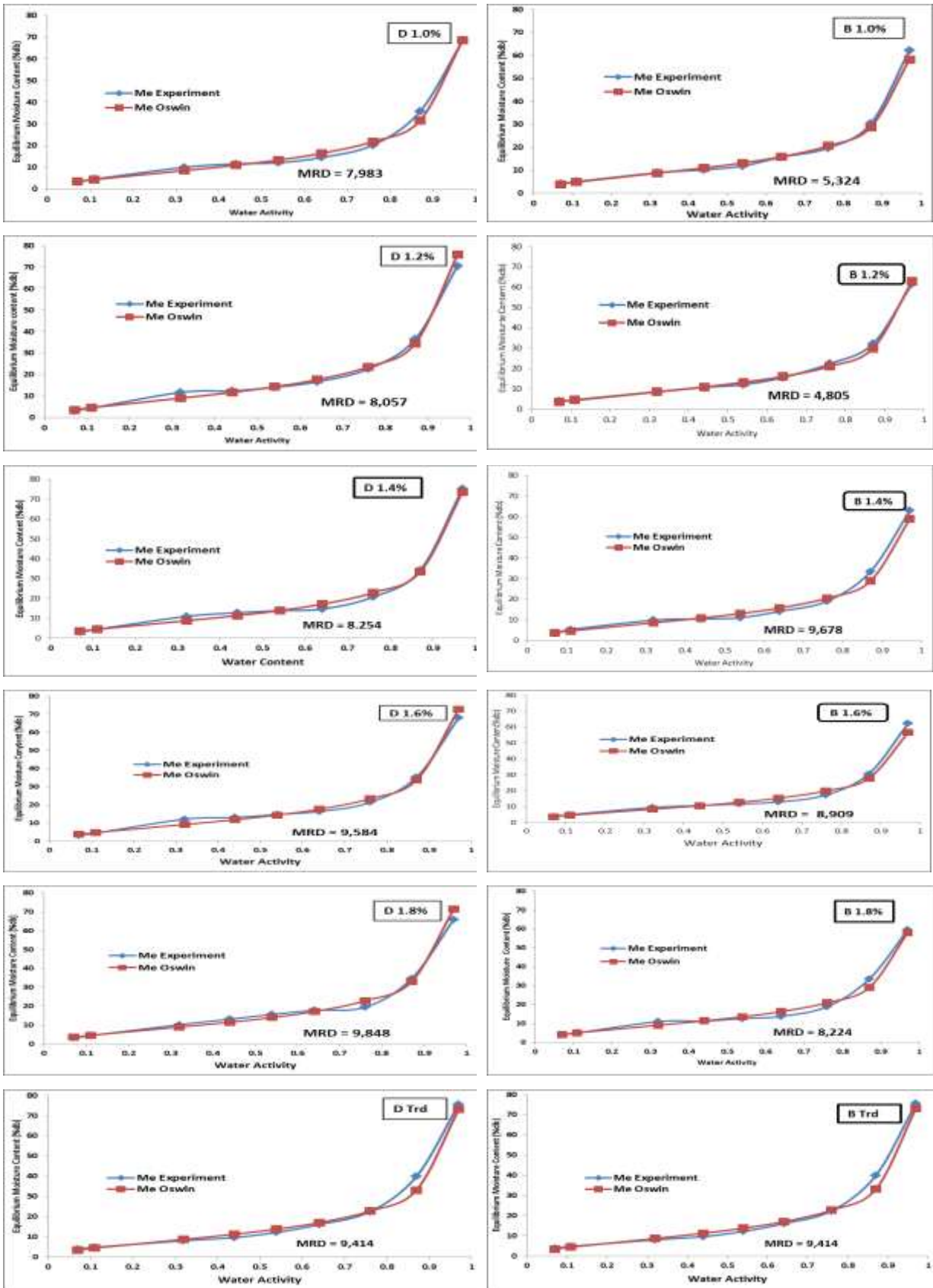


Figure 4. MSI curves of Oswin model of 12 samples Tuna's se'i made with different liquid smoke concentration and traditional Se'i. D = Dorsal and B = Bely, 1.0 to 1.8% an liquid smoke concentration and Trd is traditional method.

should be considered.

Conflict of Interests


The authors have not declared any conflict of interests.

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A wooden cutting board with a fish fillet, lemon slices, and onion slices. The fish is pinkish-red, the lemons are yellow, and the onions are white. The background is a dark, speckled surface.

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