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LTHV (LOW TEMPERATURE AND HIGH VELOCITY) DRYING CHARACTERISTICS AND MATHEMATICAL MODELING OF ANCHOVY (*ENGRAULIS ENCRASICOLUS*)

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Abstract
The main target of this work is to investigate the LTHV drying properties of Anchovy (*Engraulis encrasicolus*) experimentally. For this purpose, 100 g of anchovy samples were dried using ~7 m/s velocity and ~38% relative humidity at 4, 10, 15 and 20 °C. During the drying experiments, temperature, mass loss, drying air velocity and humidity were investigated. The weight of raw Anchovy fillets decreased from 100 g to 47.6 g at 4 °C for 25 h, 46.7 g at 10 °C for 23 h, 45.3 g at 15 °C for 20 h and 44.67 g at 20 °C for 13 h. In this context, Twenty-three common mathematical models were used on the experimental LTHV drying results. As result, the most suitable models of LTHV drying were determined for the each LTHV drying temperature. The R^2 (determination coefficient), X^2 (chi square) and *RMSE* (root mean square error) were applied to find the most suitable models. In this regard, Logarithmic (Asymptotic), Midilli-Kucuk, Demir et al, Balbay-Sahin models were chosen as the best mathematical models for each LTHV drying temperature at 4, 10, 15 and 20 °C. Consequently, the best single layer drying curve equations were chosen as the optimal models for LTHV drying of anchovy.
Keywords: Food, fish drying, thin-layer, LTHV, modeling, anchovy

HAMSİ'NİN (*ENGRAULIS ENCRASICOLUS*) LTHV (DÜŞÜK SICAKLIK VE YÜKSEK HIZ) KURUTMA KARAKTERİSTİKLERİ VE MATEMATİKSEL MODELLENMESİ

Öz
Bu çalışmanın temel amacı, Hamsinin (*Engraulis encrasicolus*) LTHV kurutma özelliklerini deneysel olarak araştırmaktır. Bu amaçla, 100 g Hamsi örnekleri ~% 38 bağıl nemde ~7 m/s hıza sahip hava kullanılarak, 4, 10, 15 ve 20 °C sıcaklıklarda kurutuldu. Deneyler sırasında ağırlık kaybı, sıcaklık, kuruma hızı ve bağıl nemi değerleri belirlenmiştir. Hamsi filetolarının ağırlığı, 4 °C'de 25 saatte, 100 g'dan 47.6 g 'a, 10 °C'de 23 saatte 46.7 g'a, 15 °C'de 20 saatte 45.3 g'a, 20 °C'de 13 saatte 44.67 g'a düşmüştür. Bu kapsamda, gözlemlenen kurutma deney verileri üzerine yirmi üç ortak matematiksel model uygulanmıştır. Sonuç olarak, Hamsinin her LTHV kurutma sıcaklığı için en uygun matematiksel modeller belirlenmiştir. En uygun modeli belirlemek için R^2 (Determinasyon Katsayıları), X^2 (Ki-Kare) ve RMSE (Tahmini Standart Hata) kullanılmıştır. Elde edilen sonuçlara göre, Logaritmik (Asimptotik), Midilli-Küçük, Demir ve diğerleri, Balbay ve Şahin, her LTHV kurutma sıcaklığı için 4, 10, 15 ve 20 °C'de en uygun matematiksel modeller olduğu belirlenmiştir. Sonuç olarak, hamsinin ince tabaka LTHV kurutma karakteristiğini en iyi temsil edecek en uygun modeller ortaya konmuştur.
Anahtar kelimeler: Gıda, balık kurutma, ince tabaka, LTHV, modelleme, hamsi

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INTRODUCTION

Anchovy (*Engraulis encrasicolus*) is a species of the *Engraulidae* family. The *Engraulidae* family includes approximately 144 species such as Black-Sea Anchovy. Fifteen percent of the total fish production of world is Anchovy (Chairi and Rebordinos, 2014). Anchovy is also the most common consumed fish species in Turkey. Approximately half of total fish production of Turkey is anchovy (Olgun and Kose, 1999). After fishing process, fresh Anchovy is commonly consumed as steamed, grilled, fish soup, fish bread etc. during fishing season. A big amount of production cannot be consumed freshly and the fresh product is processed to animal feed as a cheaper fish product. On the other hand, there is a tendency to develop alternative fish products especially based on Black sea anchovy for the anchovy marketing. In this regard, the raw material can be processed to more profitable alternative food products. These new alternative fish products should be assisted by using a more safety, sustainable and environmental friendly unit operations such as drying (Kilic et al., 2009; Kilic et al., 2010; Moraes et al., 2013). Drying process is an old food preservation method, and a common unit operation for food process. The evaporation of water content prevents microbiological quality loses in perishable food (Dincer, 1996; Dincer, 1998; Kilic and Oztan, 2013). It is clear that, water content can be decreased by drying and the spoilage of food caused by microorganism and other agents can be minimized. In addition, food drying is a safe and environmentally benign process, since it does not include any chemical preservatives which may affect environment (Kilic et al., 2009; Kilic et al., 2010). In this regard, the fish producers can produce dried or semi-dried anchovy products in fishing season. Dried anchovy product can be used as a safety product or food additive with the other common food (Kilic, 2017). There are different foods drying methods in food literature. On the other hand, total raw material quality is affected by the LTHV conditions like as process temperature. Higher temperature leads to more quality loss. In addition, the LTHV drying method can preserve quality characteristics of food (Kilic, 2009; Kosuke et al., 2016). LTHV drying method can preserve to the quality of biomaterial during the drying application. Thus, the common food degradation reactions can be reduced by the application of LTHV drying. In addition, LTHV application can preserve especially to the semi-dried bioactive foods. In addition, it is a novel environmental benign food drying method for the industry (Kilic et al., 2010; Kilic, 2017).

This paper presents an empirical study of both thin-layer LTHV drying behavior and its mathematical modeling. Thin layer drying presents an indoor drying process, which is exposed to air throughout the food product in controlled environmental conditions (Kilic, 2017; Hall, 1980; Keey, 1992). There are many works on thin layer drying in literature. However, there is not any study on LTHV drying of anchovy in literature. A selected thin layer cold drying equation can support to the standardization of fish drying and an empirical equation can be easily applied to drying (Midilli, 2001; Midilli et al., 2002; Midilli, and Kucuk, 2003; Akpinar and Bicer, 2008). There are some studies in literature about drying of Anchovy. Moraes and Pinto (2013) dried another species of anchovy (*Engraulis anchoita*) at 50, 60 and 70 °C (2.5 m/s). The drying parameters were determined to be suitable for the Henderson–Pabis model. Dongbang and Matthujak (2013) dried anchovy by using an infrared radiation at 50-70 °C (0.5-1.5 m/s).

In this paper, LTHV drying characteristics and mathematical modeling of Anchovy has just investigated. The main purposes of this work are to discuss and choose to the most suitable drying curves from the open literature for LTHV drying of anchovy. In order to reach this goal, twenty-three most common mathematical models were used (Akpinar and Bicer, 2008; Kilic, 2017). These mathematical models can be applied on the drying kinetics of perishable products (Chin and Law, 2008). The most suitable drying models can be applied to the selection of optimal drying conditions for a specific product (Kucuk et al., 2014). The optimal drying conditions of a specific product help the industry to produce high quality products. The identification of the most suitable mathematical equation is a standardization process of the single layer drying characteristics.

MATERIAL AND METHODS

Mathematical modeling

The most common twenty-three theoretic, semi theoretical and experimental mathematical models (Table 1) were studied to the LTHV drying results performing a nonlinear regression analysis. The mathematical modeling of experimental data were carried out using the Statistica 7 Computer Program for single layer with 0.5 cm at different drying air temperatures (4, 10, 15 and 20 °C). Weight loss was found using equation (1) depending on the weight changes of raw material during low temperature drying (Kilic, 2009).

$$M = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where M is the weight loss; M_0 is material weight at t= 0; M_e the material weight at the equilibrium time and M_t is raw material weight at t (Kilic, 2009).

The variation of anchovy moisture during the LTHV drying was identified with the equation (2) (Kilic, 2009). Water content of raw materials were determined using a weight lost to be based on LTHV drying time during the process. The equation (2) was applied to find the material moisture (Kilic, 2009).

$$W = \frac{M_t - M_e}{M_0} x100 \tag{2}$$

where W is the moisture of material; M_0 is the fish weight at t = 0; M_e is the material weight at equilibrium point and Mt is the raw material weight at t (Cyprian et al., 2015; Kilic, 2017).

The mass shrinkage was founded with equation (3) (Cruess, 1958; Kilic, 2017).

$$S_{mr} = \frac{M_t(t)}{M_0(t=0)} \tag{3}$$

where S_{mr} is the mass shrinkage ratio of fish; M_0 is material weight at t = 0; M_e is the material weight at the drying equilibrium point and Mt is the sample mass at t (Kilic, 2017).

Drying rate of Anchovy samples when LTHV drying were calculated with Eq. (4).

$$\frac{dM}{dt} = \frac{M_{t+\Delta t} - M_t}{\Delta t} \tag{4}$$

In where dM/dt is the rate of LTHV drying at any cold drying time, $M_{t+\Delta t}$ is moisture of material at t = t + Δt and M_t presents weight of material at t = t (Kilic, 2017).

Table 1 shows to the applied thin-layer drying curve equations.

In order investigate to the suitability of the fit the correlation determination coefficient (R^2), the reduced Chi-Square (X^2) and the smallest Root Mean Square Error (RMSE) were used. A nonlinear regression analysis was applied by using Statistica 7. The most suitable models for LTHV were chosen base on the maximum values of R^2, X^2 and the smallest RMSE by using Eq. (5, 6, 7) (Jan et al., 2014; Kucuk et al., 2014; Kilic, 2017).

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{5}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N-n} \tag{6}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2}{N}} \tag{7}$$

where $MR_{\exp,i}$ presents to the observed fish moisture, $MR_{pre i}$ presents to the predicted moisture for LTHV application on Anchovy. *N* shows the number of experiment, MRexp is the average data, *Z* gives to the constant numbers and *i* is data at *t = 0* (Kucuk et al., 2014; Kilic, 2017).

Experimental Setup

A laboratory type LTHV compact system was used for experimental production. The diagram of experimental set-up for drying process is given in Figure 1 schematically. The LTHV drying system was included a compressor, an air evaporator and two circulatory radial fans (Kilic, 2009). Figure 1shows the design of LTHV drier unit schematically.

Table 1. The Applied Drying Curve Equations (*Modified from Kucuk, et al., 2014; Kilic, 2017*)

No	The Name of Mathematical Model	Equation
1	Simplified Fick's diffusion (SFFD)	$MR = a\exp\left(-c\left(\frac{t}{L^2}\right)\right)$
2	Weibull	$MR = \exp\left(-\left(\frac{t}{a}\right)^b\right)$
3	Aghbashlo et al	$MR = \exp\left(-\frac{k_1 t}{1+k_2 t}\right)$
4	Parabolic	$MR = a + bt + ct^2$
5	Balbay and Şahin	$MR = (1-a)\exp(-kt^n) + b$
6	Alibas (Modified Midilli-Kucuk)	$M_R = a\exp(-kt^n) + bt + g$
7	Thompson	$t = a\ln(MR) + b(\ln(MR))^2$
8	Wang and Singh	$MR = 1 + at + bt^2$
9	Hii et al	$MR = a\exp(-kt^n) + c\exp(-gt^n)$
10	Newton (Lewis, Exponential, Single exponential)	$MR = \exp(-kt)$
11	Verma et al (Modified Two-Term Exponential)	$MR = a\exp(-kt) + (1-a)\exp(-gt)$
12	Approximation of Diffusion (Diffusion approach)	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$
13	Modified Henderson and Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$
14	Midilli-Kucuk (Midilli, Midilli et al)	$MR = a\exp(-kt^n) + bt$
15	Henderson and Pabis (Single term)	$MR = a\exp(-kt)$
16	Logarithmic (Asymptotic) Yagcioglu et al	$MR = a\exp(-kt) + c$
17	Demir et al	$MR = a\exp(-kt)^n + b$
18	Two-Term	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$
19	Two-Term Exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$
20	Page	$MR = \exp(-kt^n)$
21	Modified Page	$MR = \exp(-(kt)^n)$
22	Modified Page-I	$MR = \exp((-kt)^n)$
23	Modified Page-II	$MR = \exp\left(-c\left(\frac{t}{L^2}\right)^n\right)$

LTHV dryer system had 30 cm diameter stainless steel three trays. The LTHV drier cabinet was controlled by a digital unit for the standard control parameters like as air velocity, temperature and humidity with sensitive sensors, and all these observed results were recorded to the system computer by a software installed micro processing control unit (Kilic, 2017).

A radial fan was attached to the inlet of LTHV drying unit. During the LTHV drying process, a sensitive digital balance (0.00±0.1 digit) was used to weight the anchovy samples. The velocity of drying air was determined by a multifunction infrared anemometer (0.00±0.1 digit TA2 model). All temperature of LTHV units were measured with an infrared multifunctional thermometer (0.00±0.1 digit) (Kilic, 2017).

Sample preparation

Anchovy samples (*Engraulis encrasicolus*) was provided by a local fisherman from Black Sea for LTHV drying experiments. Anchovy with an average weight of ~100 g was *gutted, trimmed, slaughtered, washed, dried* and *analyzed*. An average 100 g of Anchovy meat from the raw materials were taken randomly to the determination of raw material characteristics before LTHV drying process. The LTHV Drying process were performed at 4, 10, 15 and 20 °C in 7 m/s±0.1 of air velocity perform to the drying of raw material. At the beginning of LTHV cycle, the fish moisture ratio was investigated for cold drying (Kilic, 2017; Kilic, 2009). a_w values of the raw and processed material were identified by a Sensitive (±0.003) Aqua Lab Model cx2. 10 g of raw and dried fish material were used by an oven at ±105 °C for the identification of moisture and equilibrium moisture content. The fat, ash, salt, moisture, protein and pH value were determined by AOAC standard methods (1995).

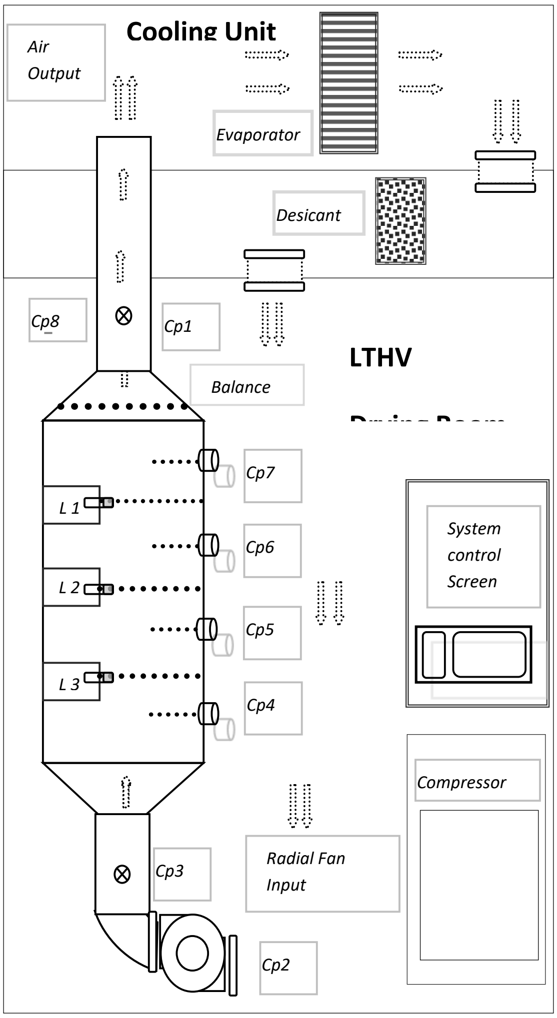

Figure 1. The Detailed presentation of the LTHV Drying System *(Modified from Kilic, 2017)*

It was accordingly found that the initial moisture content of Anchovy had approximately 66.4%(wb). The fish samples were prepared for the thin layer drying experiments. LTHV drying air was performed at 7 m/s to decrease the negative effect of cold drying on drying rate (Kilic, 2017; Putra and Ajiwiguna, 2017). The Anchovy fillets were prepared in sizes of 0.5x3x5 cm and ~100 g of the samples was placed on the mesh-wire containers. All LTHV drying processes were carried out at 40-50% RH. During the drying processes, the wet and dry bulb temperature drying air inlet and outlet temperatures, laboratory temperature and inside temperature of dryer, weight losses of the fish and LTHV drying air velocity were measured for half an hour. A process flow chart for the LTHV drying process of anchovy was given in Figure 2.

RESULTS AND DISCUSSION

Low temperatures high velocities drying process is a thin-layer indoor drying application that applied at low temperatures and high velocities (Kilic, 2017; Kilic 2009). The single layer LTHV applications for Anchovy with a sample thickness of 0.5 cm were conducted at 4, 10, 15 of 20 °C. The sample moisture content, weight loss, mass shrinkage and temperatures were found as the function of LTHV drying time. The parameters and uncertainties of the LTHV drying of anchovy are given in Table 2.

There are not any drying data related to LTHV drying characteristics of anchovy in food literature. This LTHV drying study gives important experimental results that contribute to the future of scientific and industrial studies in food. The weight of raw Anchovy fillets were decrease from 100 g to 47.6 g at 4 °C for 25 h, 46.7g at 10 °C for 23 h, 45.3 g at 15 °C for 20 h and 44.67 g at 20 °C for 13 h. These results have similarities with the LTHV drying properties of Trout (Kilic, 2017). Kilic (2009) identified that the weight of Trout decreased from 100 g to 55.5 g at 4 °C in 26 h, 56 g at temperature of 10 °C in 23.5 h, 55 g at temperature of 15 °C in 21.5 h and to 56 g at temperature of 20 °C after 13.5 h by the similar LTHV drying conditions.

The air velocity of LTHV was fixed in average 7 m/s during the drying application to increase drying performance of low drying temperature. Figure 3 presents the variations of the observed cold air velocity values during the LTHV drying process (Kilic, 2017).

Table 2. The Observed Parameters of LTHV Unit (*Modified from Kilic, 2017*)

	LTHV Drying conditions					
Parameters of LTHV Drying	T_4	T_{10}	T_{15}	T_{20}		
Sample thickness	0.5	0.5	0.5	0.5	±0,2	cm
Sample length	5	5	5	5	±0.1	cm
Sample width	3	3	3	3	±0.2	cm
Initial sample weight	100	100	100	100	±0.1	g
Final sample weight	47.6	46.7	45.3	44.67	-	g
Initial moisture content (wb)	66.45	66.42	66.47	66.44	±0.03	%
Wide of the sample	10	10	10	10	±1.0	mm
Total drying time	25	23	20	13	-	h
LTHV air drying temperature	4	10	15	20	±1	ºC
LTHV air drying velocity	7	7	7	7	±0.5	m/s
System inlet temperatures	4	10	15	20	±1	ºC
System outlet temperatures	5	11	16	21	±0.01	ºC
System inlet relative humidity	38	38	38	38	±5	%
System outlet relative humidity	38.5	38.5	38.5	38.5	±5	%

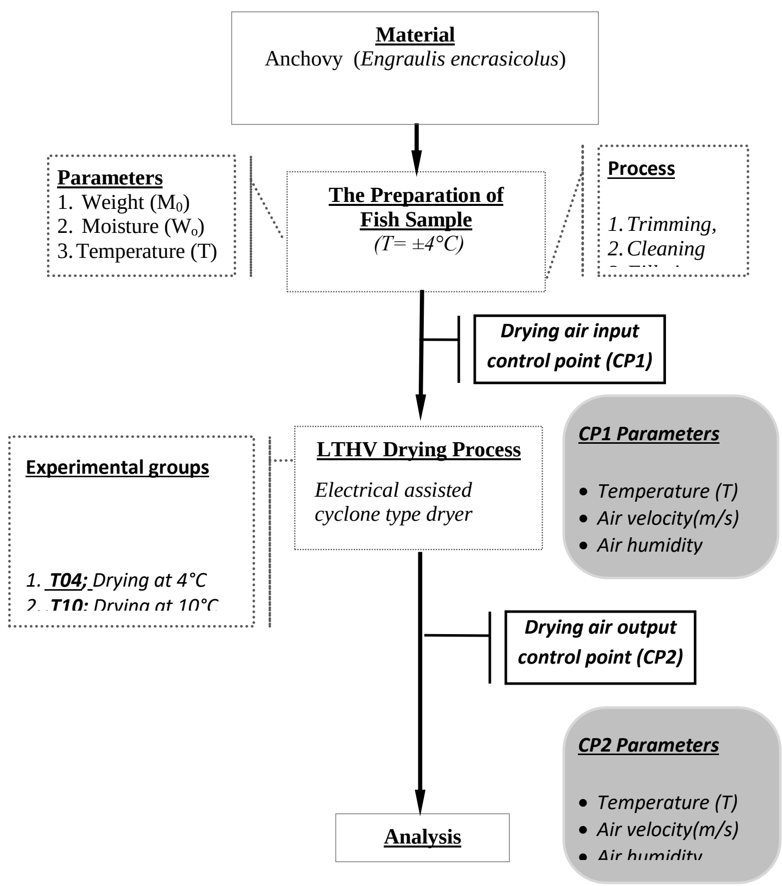

Figure 2. Flow Chart of LTHV Thin Layer Drying of Anchovy *(Modified from Kilic, 2017)*

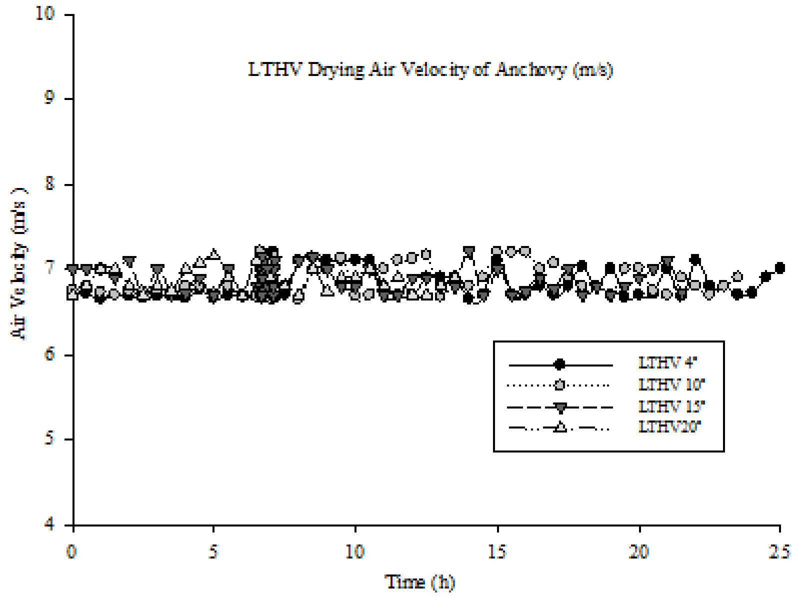

Figure 3. The observed LTHV air velocity values during the drying process of the LTHV Drying (*Kilic, 2009*)

Drying rate of Anchovy for the each LTHV drying air temperature was observed using Eq. (4). The drying rate decreased as logarithmically by the progressing drying time. Drying rate of Anchovy at 4 °C decreased to zero after 25 hours. It is clear that the LTHV drying rate of anchovy is based on especially free water content of raw fish, and the low temperature drying air. Figure 4 presents the variations of LTHV drying rate depending on time (Kilic, 2009; Kilic, 2017).

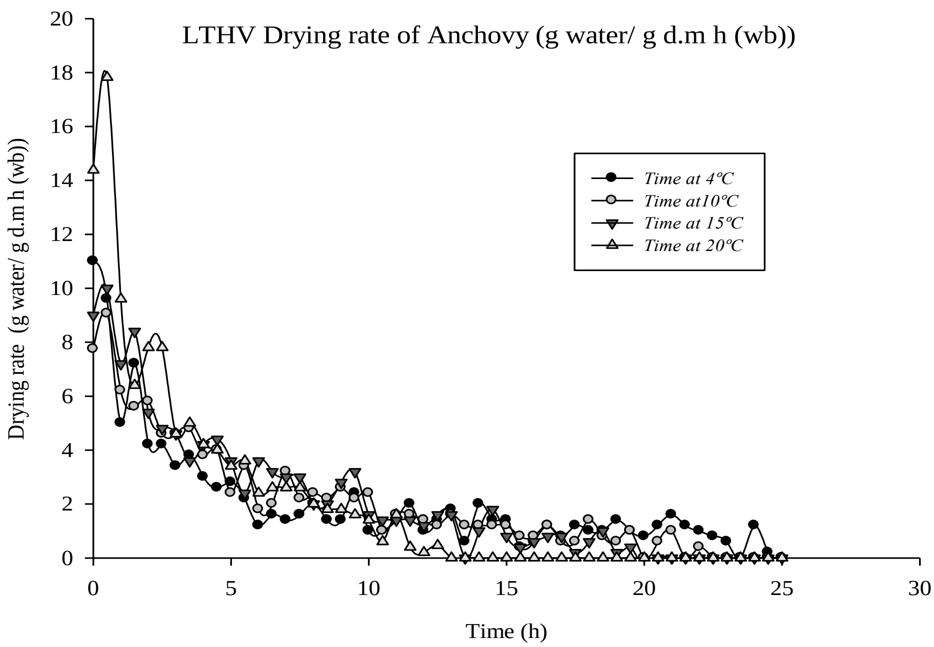

Figure 4. The variations of drying rate as a function of drying time (*Modified from Kilic, 2009*).

As a new food drying method, LTHV cold drying process is more conservative on food and fish especially at 4 °C. LTHV cold drying method can support to the quality properties of food and especially perishable, semi dried and functional foods. The LTHV drying period was included the falling rate cycle and constant rate cycle. In addition to these, the differences in LTHV drying rate at 4 °C were significant from the other LTHV drying temperatures like as 10, 15 and 20 °C for constant rate period statistically ($p<0.05$). The identification of the most suitable drying curve equations can contribute researchers and especially industry to the selection of most suitable drying conditions (Kilic, 2017; Kilic, 2009).

LTHV Drying Modeling and Evaluation

Tables 3 gives to the results of evaluation to select the most suitable drying equation of the LTHV drying of anchovy for 4, 10, 15 and 20 °C respectively.

Table 3 presents to the evaluation criteria of LTHV drying of Anchovy at 4, 10, 15 and 20 °C (Kilic, 2017).

Table 3. Evaluation Criteria for LTHV Drying of the Anchovy (*Modified from Kilic, 2017*)

No	Model Name	Evaluation values of LTHV Drying Groups											
		LTHV at 10ºC			LTHV at 10ºC			LTHV at 15ºC			LTHV at 20ºC		
		R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE
1	*Newton Lewis*	0.9924	0.0021	0.0473	0.9927	0.0021	0.0334	0.9962	0.0025	0.0241	0.9945	0.0025	0.0259
2	*Page*	0.9919	0.0012	0.0544	0.9934	0.0024	0.0447	0.9953	0.0033	0.0316	0.9922	0.0044	0.0357
3	*Modified Page*	0.9948	0.0018	0.0388	0.9971	0.0028	0.0506	0.9979	0.0038	0.0388	0.9939	0.0036	0.0376
4	*Modified Page-I*	0.9974	0.0016	0.0334	0.9966	0.0016	0.0372	0.9965	0.0025	0.0285	0.9955	0.0021	0.0411
5	*Modified Page-II*	0.9934	0.0017	0.0403	0.9948	0.0012	0.0317	0.9962	0.0019	0.0211	0.9972	0.0018	0.0288
6	*Henderson & Pabis*	0.9919	0.0019	0.0337	0.9963	0.0017	0.0377	0.9943	0.0034	0.0356	0.9918	0.0027	0.0433
7	*Logarithmic*	0.9989	0.0012	0.0178	0.9995	0.0009	0.0222	0.9994	0.0004	0.0115	0.9992	0.0008	0.0211
8	*Midilli- Kucuk*	0.9997	0.0023	0.0225	0.9989	0.0006	0.0184	0.9993	0.0011	0.0233	0.9994	0.0011	0.0147
9.	*Demir et al*	0.9999	0.0006	0.0188	0.9984	0.0006	0.0266	0.9989	0.0008	0.0143	0.9988	0.0029	0.0107
10	*Two-Term*	0.9952	0.0019	0.0373	0.9985	0.0009	0.0139	0.9988	0.0005	0.0109	0.9931	0.0027	0.0456
11	*Two-Term Exponential*	0.9955	0.0018	0.0347	0.9945	0.0012	0.0358	0.9964	0.0045	0.0270	0.9919	0.0023	0.0399
12	*Verma et al*	0.9971	0.0018	0.0399	0.9959	0.0025	0.0324	0.9925	0.0054	0.0255	0.9959	0.0026	0.0412
13	*Approximation Diff.*	0.9948	0.0016	0.0451	0.9996	0.0008	0.0125	0.9977	0.0031	0.0341	0.9974	0.0042	0.0599
14	*Modified Henderson*	0.9941	0.0011	0.0376	0.9992	0.0007	0.0196	0.9956	0.0038	0.0412	0.9965	0.0061	0.0471
15	*Thompson*	0.9932	0.0014	0.0406	0.9988	0.0010	0.0122	0.9993	0.0008	0.0191	0.9949	0.0034	0.0276
16	*Wang and Singh*	0.9864	0.0022	0.0324	0.9899	0.0032	0.0674	0.9926	0.0027	0.0478	0.9974	0.0031	0.0577
17	*Hii et al*	0.9956	0.0028	0.0372	0.9996	0.0011	0.0133	0.9987	0.0009	0.0143	0.9970	0.0018	0.0435
18	*Simplified Fick diff,*	0.9971	0.0023	0.0334	0.9991	0.0008	0.0112	0.9962	0.0025	0.0456	0.9943	0.0019	0.0433
19	*Weibull*	0.9938	0.0018	0.0416	0.9921	0.0025	0.0347	0.9977	0.0039	0.0342	0.9948	0.0029	0.0533
20	*Aghbashlo et al*	0.9814	0.0631	0.0318	0.9990	0.0011	0.0127	0.9991	0.0006	0.0180	0.9977	0.0044	0.0221
21	*Parabolic*	0.9766	0.0031	0.0817	0.9993	0.0009	0.0101	0.9744	0.0091	0.0446	0.9923	0.0041	0.0344
22	*Balbay and Şahin*	0.9989	0.0016	0.0231	0.9992	0.0007	0.0169	0.9987	0.0011	0.0190	0.9976	0.0038	0.0351
23	*Alibas*	0.9993	0.0008	0.0294	0.9974	0.0032	0.0397	0.9911	0.0034	0.0421	0.9912	0.0033	0.0489

The smallest values of RMSE (the root mean square error), the highest R^2 (determination coefficient) and χ^2 (the chi-square) give the most suitable model that describe LTHV drying characteristics for the anchovy (Jan et al., 2014; Kilic, 2017).

Table 3 gives to the Midilli Kucuk, Demir et al, Logarithmic, Balbay and Şahin and Alibas as the selected most suitable models for LTHV thin layer anchovy drying at 4 °C with 7 m/s cold air velocity. Midilli- Kucuk, Demir et al, Logarithmic, Approximation Diff., Thompson, Hii et al, Balbay and Şahin, Aghbashlo et al, Simplified Fick diff., Modified Henderson, Two-term and Time- Parabolic models presents the most suitable models for thin layer drying of anchovy at 10 °C with 7 m/s air drying velocity. Midilli Kucuk, Logarithmic, Hii et al, Demir et al, Thompson**,** Aghbashlo et al, Balbay and Şahin and Two-Term models were chosen as the most suitable eight model for thin layer drying of anchovy at 15 °C by 7 m/s cold air velocity. Logarithmic, Midilli Kucuk, Demir et al, Balbay and Şahin were chosen the most suitable four models for drying of anchovy at 20 °C (Kilic, 2017).

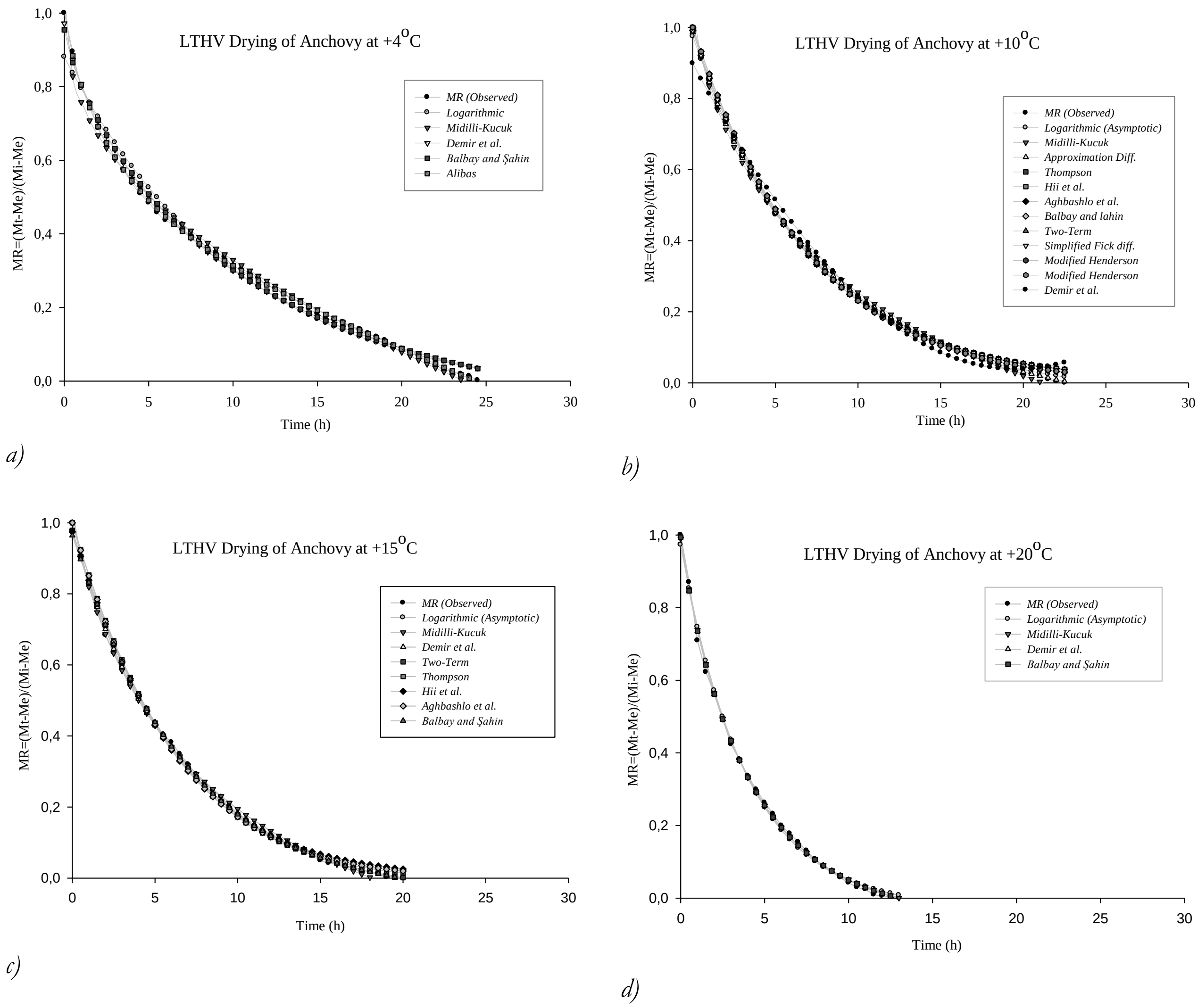

Figure 5. *(a, b, c, d)*. Comparison of Predicted and Observed Moisture Ratio with Time Depending (*Kilic, 2017*)

Figure 5 *(a, b, c, d)* presents predicted and observed dimensionless moisture ratio according to LTHV drying time comparatively and gives the most suitable common models of the LTHV drying models at different temperatures. The experimental applications of LTHV were applied for single layer LTHV drying modeling of anchovy (*E. encrasicolus*) with twenty-three most preferred mathematical models. In this regard, Logarithmic (Asymptotic), Midilli Kucuk, Demir et al, Balbay and Sahin were chosen the most suitable mathematical models for each temperature (4, 10, 15 and 20 °C). On the other hand, some models were chosen the most suitable model for the specific temperature application of LTHV (Kilic, 2017).

Figure 5

Figure 6. *(a, b, c, d)* gives a comparison of observed MR depending on the predicted MR of LTHV drying at 4, 10, 15 and 20 °C. The most suitable models were identified by the R^2, RMSE and χ^2 as the statistical criteria (Kilic, 2017).

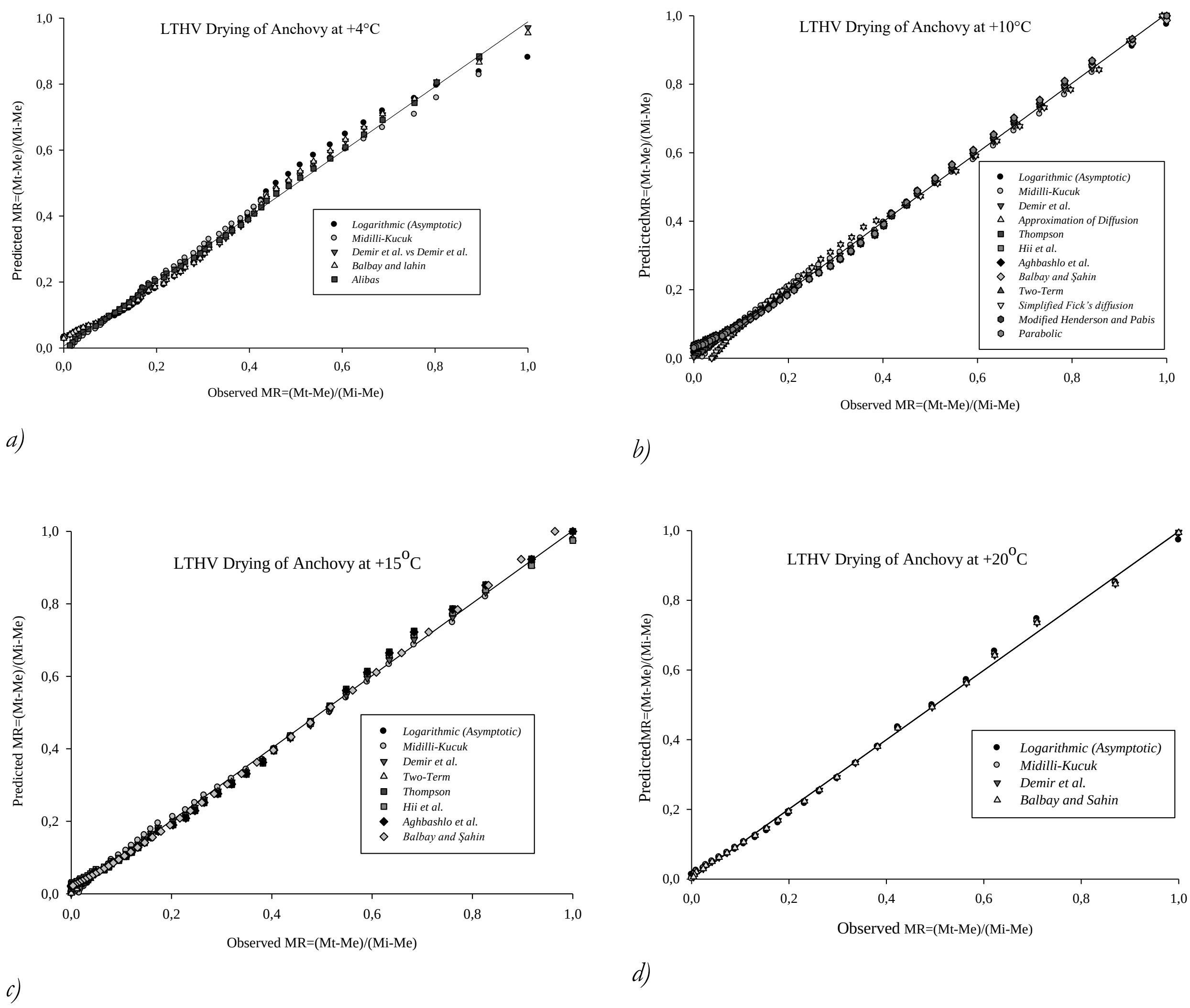

Figure 6. *(a, b, c, d)*. Comparison of Observed Moisture Ratio with Predicted Values (*Kilic, 2017*)

We observed a good agreement between the observed and estimated moisture content of LTHV. These results seem to have a good agreement with the values observed by Kilic (2017) that Midilli Kucuk, Logarithmic, Hii et al, Demir et al, Balbay-Şahin and Alibas were chosen for the LTHV application as the most suitable six models at 4 °C (Kilic, 2017).

Conclusions

In this work, a LTHV application was applied for single layer drying of anchovy (*E. encrasicolus*) by using twenty-three most common mathematical drying models. All these semi theoretic and experimental mathematical models were used for the observed LTHV cold drying values performing non-linear regression analysis with Statistica software for single layer at different drying air temperatures of 4, 10, 15 and 20 °C (Midilli and Kucuk, 2003; Holl, 1980; Kilic, 2017).

According to these results of the research, some conclusions are drawn as below;

-Logarithmic (Asymptotic), Midilli-Kucuk, Demir et al, Balbay and Şahin and Alibas were chosen as the most suitable five model for thin layer drying of anchovy at 4 °C (Kilic, 2017).

-Logarithmic, Midilli-Kucuk, Demir et al, Approximation Diff., Thompson, Hii et al, Aghbashlo et al, Balbay and Şahin, Two-term, Simplified Fick diff., Modified Henderson and Pabis, Time- Parabolic models were chosen as the most suitable models for Anchovy at 10 °C (Kilic, 2017).

-Logarithmic (Asymptotic), Midilli-Kucuk, Demir et al, Thompson**,** Hii et al, Aghbashlo et al, Balbay and Şahin and Two-Term models were chosen as the most suitable eight model for LTHV drying of anchovy at 15 °C with 7 m/s drying air velocity (Kilic, 2017).

-Logarithmic (Asymptotic), Midilli-Kucuk, Demir et al, Balbay and Şahin models were chosen as the most suitable four models for LTHV drying of anchovy at 20 °C (Kilic, 2017).

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