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Effects of varied drying methods on the proximate composition, sensory qualities, and rehydration characteristics of mud eel (*Monopterus cuchia*)

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Abstract

Mud eel (*Monopterus cuchia*) is a tasty, medicinally valuable, nutritionally rich amphibious freshwater fish predominantly found in Bangladesh. This study aimed to investigate the impact of drying on the proximate compositions, sensory, and rehydration characteristics of dried mud eel. The fish were longitudinally sliced into fillets with an average thickness of 0.5–0.8 cm and then dried at different drying methods with or without pretreatment of 10% salt (NaCl). The Peleg's and Arrhenius models were applied to fit the rehydration kinetics data. The current result revealed that the proximate composition varied with the drying methods *viz*. moisture (10.54-20.73%), protein (59.47-75.80%), lipid (2.08- 3.84%), and ash (11.53-17.44%). Sun-dried mud eel had the better result for all sensory parameters except color, which was found to be higher in smoke-dried mud eel. Peleg's model described the water hydration data and equilibrium moisture content for all dried samples between 28 and 60°C. The coefficient, which was always very high (R^2>0.90), shows that Peleg's model fits the experimental data well at all temperatures. For all dried mud eel samples, except for oven-, smoke-, and salt-treated oven-dried samples, Peleg's constant K_1 declined linearly as the hydration temperature rose from 28 to 60°C. Peleg's capacity K_2 decreased with the increment of soaking water temperature except for oven-dried samples. The highest equilibrium moisture content results in samples treated with salt, which indicates that salt prevents tissue disruption during drying. All samples' activation energy (Ea) value was 8.08-25.99 kJ/mol. Overall, this study addresses mud eel that could be dried with sun drying followed by oven drying and salt-treated smoke drying for reliable outputs.

1. Introduction

The mud eel (*Monopterus cuchia*), a freshwater air-breathing fish species, belongs to the Synbranchidae family (Hangzo *et al.,* 2017) and is widely distributed across Southeast Asian countries like Bangladesh, India, and Pakistan. In Bangladesh, they are known as cuchia and are commonly found in open water bodies such as rivers, haors, baors, beels, canals, and floodplains. Among various mud eel species in Bangladesh, *Monopterus cuchia* holds significant economic value due to its high domestic and international demand. Bangladesh made 25.37 million USD in 2016-2017 from the export of over 1.3 million metric tons of mud eel (Islam *et al.,* 2020). After fulfilling domestic needs, Bangladesh has exported live mud eel to around 15 countries (Hasan *et al.,* 2012). The nutritional value of mud eel is high. As a versatile nourishment commodity, mud eel is a decent source of protein, lipids, essential amino acids, fatty acids, and tiny amounts of minerals, which support its reputation as a highly nutritious food

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source (Faruque *et al.,* 2019).

In Bangladesh, the ethnic community, most of the consumers of this fish still believe in the therapeutic properties of mud eel and use the treatment of various ailments such as asthma, hemorrhoids, weakness, anemia, and diabetes. This fish's blood, combined with herbs to treat diabetes and baldness, has also been reported. It is thought that eating the fish's gall bladder, either fresh or sun-dried, will provide anti-asthmatic and anti-rhinitis effects. The dried head of fish is fried with *Garcinia peduculata* (Roxb.) and taken as a hemorrhoid cure (Rahman *et al.,* 2024).

When fish are harvested, handled, and processed properly and on schedule, they may provide humans with a source of protein and generate foreign exchange for many people. However, degradation of meat quality has always been a burning issue in fish preservation (Cao *et al.,* 2019). Various drying methods are employed as effective preservation techniques to extend the shelf life and make mud eel available year-round (Abraha *et al.,* 2018; Kamal *et al.,* 2023). Among these, sun drying, oven drying, solar drying, and smoke drying are commonly used to process fish. Different processing methods of fish affect their chemical, physical, and nutritional compositions.

Sun drying is cost-effective and environmentally friendly but heavily reliant on favorable weather conditions and susceptible to microbial contamination and nutrient degradation due to uncontrolled exposure (Kamal *et al.,* 2023). Oven drying allows for more control over temperature and drying rate, leading to consistent quality and reduced contamination risk. However, it can be energy-intensive and may reduce some heat-sensitive nutrients (Abraha *et al.,* 2018). Smoke drying, on the other hand, enhances flavor and offers natural antimicrobial effects but may alter the taste profile and introduce potentially harmful compounds like polycyclic aromatic hydrocarbons (PAHs) due to smoke exposure (Okpala and Ekechi, 2014). These drying methods affect not only the proximate composition and sensory attributes of dried fish but also influence rehydration characteristics. It is sometimes regarded as a measure of the material's injury from drying and other treatment methods (Okpala and Ekechi, 2014). In this regard, Peleg's model could be proposed as the best option for describing the rehydration characteristics of dried products (Peleg, 1988).

In recent studies, some novel preservation methods, such as chlorogenic acid osmosis and chitosan-based coatings, have shown promise in enhancing storage stability and retaining sensory qualities in fish. Chlorogenic acid has effectively reduced deterioration during storage (Cao *et al.,* 2020), and combined chlorogenic acid-chitosan coatings have enhanced antioxidant and antimicrobial properties, particularly in cold-stored fish (Cao *et al.,* 2019). Similarly, chitosan and hydroxypropyl starch polysaccharides have effectively preserved the physico-chemical properties of fish, highlighting a promising area for extending the shelf life of processed fish like *Monopterus cuchia* (Cao *et al.,* 2022).

Most researchers have focused on seasonal variation and the nutritional composition analysis of raw and dried mud eel. Limited information is available on how different drying methods, especially when combined with different levels of pretreatments before other drying methods, affect rehydration characteristics and consumer acceptance. However, no or limited reports are available to study dried mud eel to the best of our knowledge. This study aimed to address this gap by investigating the effects of sun drying, oven drying, and smoke drying on the proximate composition, sensory qualities, and rehydration characteristics of dried mud eel. The findings will contribute to optimizing drying practices for better quality and shelf stability of this economically important fish.

2. Materials and methods

2.1 Sample collection

Uniform-size and weight live mud eel (known as Cuchia in Bangladesh) samples were purchased from the local market of Muktagacha Upazila, Mymensingh, Bangladesh. The average weight of fish was between 250-300 g during the collection, and the length was between 36-45 cm. After that, the collected live mud eel was carefully transported to the Department of Fishing and Post-Harvest Technology laboratory, Sher-e-Bangla Agricultural University, Dhaka, and stored at −40°C for further processing and analysis.

2.2 Sample preparation

Firstly, the head and tails of the mud eel were separated and cut in the middle of the grave. Then, the abdomens were cut vertically, and the entrails were removed. The fish were then thoroughly washed with clean water to remove ear-type blood. After that, the washed fish were sliced longitudinally and made into fillets with an average thickness between 0.5 and 0.8 cm. Then, all fillets were rewashed to remove the remaining blood and put in a perforated basket for air drying for 10 mins.

2.3 Pretreatment with salt

Clean raw mud eel fillets were immersed into three

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plastic buckets containing 10% salt (NaCl) solution for 10 mins. After that, salt-treated raw fillets were subjected to air-drying at room temperature (30±2°C) for 10 mins. Air drying was necessary to condition the fish with brine solution. Then, the fish fillets were placed to dry in a smoking kiln, ring tunnel dryer (sun drying), and oven dryer.

2.4 Drying condition

2.4.1 Sun drying

Sliced fish fillets were then put into a ring tunnel dryer in three layers set on a multistoried building roof for drying with direct sunshine. The surrounding atmosphere's average temperature was recorded as 30±2°C, humidity at 84% in July-September, and the inside of the tunnel containing fish fillets was 40±2°C by a thermometer. The sample was dried for 16 hrs from 09.00 to 17.30 for two consecutive days. After drying, the dried fish fillets were ground to form a powder. Then, the fish powder was filled in a polythene bag for further analysis.

2.4.2 Oven drying

Raw mud eel fillets were put in a hot air oven (Model: DSO-500D/DSO-500DF) for drying at 60°C. Sometimes, the sample was checked to avoid burning. The fillets were kept in the oven for about 8 hrs to completely dry. After drying, the pieces were ground to form a powder and then stored in a polythene bag until use.

2.4.3 Smoke drying

After cleaning, raw fillets were put into a smoking kiln consisting of different chambers. Burning components, such as wood chips atop an iron bowl, were used in the kiln's lower portions to create a steady stream of hot smoke. During the smoking process, a sensitive thermometer measured the temperature of the smoke within the smoking kiln. The smoking kiln's temperature was maintained between 50 and 55°C by manually controlling the smoking chamber's outflow. Occasionally, fillets were turned upside down during smoking, and drying procedures continued until 9 hrs. After that, dried fillets were ground and filled into a polyethylene bag for further analysis.

2.5 Physicochemical analysis of dried mud eel

2.5.1 Determination of moisture

The moisture content of the dried mud eel was determined according to the modified method reported by Rana *et al.* (2020). A dried sample (5 g) was taken in a clean, dry, and pre-weighed crucible. Then, the crucible was transferred to the oven (Model: BST/HAO-1122) and dried at 105°C for 16 hrs. After that, it was cooled at the desiccator and weighed. Again, it was transferred to the oven and dried until a constant weight was obtained. Finally, it was cooled and weighed. The following equation was used to calculate the moisture content:

$$\%\ \text{Moisture} = \frac{W_1 - W_2}{W} \times 100 \quad (1)$$

Where W_1 = weight of sample with crucible, W_2 = weight of dried sample with crucible, W = weight of sample

2.5.2 Determination of protein

The protein content (N_2) of dried mud eel was determined using the Kjeldahl apparatus according to the method reported by Shakil *et al.* (2019) and Akter *et al.* (2023). Dried fish powder (1 g), Selenium powder (1 g), $CuSO_4$ (0.1 g), and K_2SO_4 (10 g) were taken in a volumetric flask. After that, 25 mL of H_2SO_4 (conc.) was added to it. Then, the volumetric flask was heated at 100°C for 3 hrs and cooled for 20 mins at ambient temperature.

At the end of the digestion, 300 mL of distilled water and 125 mL of 40% NaOH were added to the volumetric flask. Then, 25 mL of 4% boric acid solution and 2-3 drops of mixed indicator were added to the conical flask. The volumetric flask was attached to one end of the condenser, and the conical flask was associated with the other end. A 150 mL condensate was collected by continuous heating of the volumetric flask. After disconnecting, the conical flask was taken for titration and titrated against 0.2 N of H_2SO_4 solution. The endpoint was indicated by an orange color. The N2 content was calculated with Equation (2) while the protein content was calculated with Equation (3).

$$\%\ \text{of}\ N_2 = \text{Burette reading} \times \text{Normality of}\ H_2SO_4 \times \text{mL equivalent of}\ N_2 \quad (2)$$

$$\%\ \text{Protein} = \%\ \text{of}\ N_2 \times \text{Protein factor (6.25)} \quad (3)$$

Where the normality of H_2SO_4 = 0.2 mL equivalent of N_2 = 1.4

2.5.3 Determination of lipid

The lipid content of dried mud eel was determined according to the method described by Khan *et al.* (2021) with a slight modification. In a thimble, a 5 g fish sample was taken. Then, the thimble was put into the Soxhlet apparatus (Model: SZF-06A/SZF-06C), which was connected to 200 mL ether containing a round bottom flask. The extraction was continued for 16 hrs. After that, ether was evaporated by heating at 80°C until the flask was completely dried. The following formula calculated lipid content:

$$\%\ \text{lipid} = \frac{W_1 - W_2}{W} \times 100 \quad (4)$$

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Where W_1 = weight of the evaporated flask with sample, W_2 = empty flask weight, W = sample weight

2.5.4 Determination of ash

The ash content of dried mud eel was determined according to the method reported by Rana *et al.* (2020) with slight modifications. A total of 5 g of dried sample were measured and transferred to a clean, dry, and pre-weighed crucible. Then, the crucible was kept in a muffle furnace (Model: ACMAS ATI-118-A) at 550°C for 6 hrs. It was cooled at the desiccator and weighed. The following equation calculated the ash content:

$$\%\,\text{Ash} = \frac{W_1 - W_2}{W} \times 100 \qquad (5)$$

Where W_1 = weight of ash with crucible, W_2 = weight of the empty crucible, W = weight of the sample

2.5.5 Rehydration kinetics

According to Peleg's model, the rehydration kinetics of dried mud eel was carried out, as Maharaj and Sankat (2000) reported. Peleg's equation is as follows:

$$M_t = M_o + \frac{t}{K_1 + K_2 t} \qquad (6)$$

As t Þ0

$$\frac{dM_t}{dt} = \frac{1}{K_1} \qquad (7)$$

And as for t Þ ∞

$$M_e = M_o + \frac{1}{K_2} \qquad (8)$$

Where K_1 is the Peleg's constant (min per % db), K_2 is the Peleg's capacity constant (reciprocal of % mc db), and M_e is the equilibrium moisture content (% mc db), M_t is the moisture content (%db) at time t. t is the rehydration time (min) (Maharaj and Sankat, 2000).

The linear version of Peleg's equation is provided in equation (9) as follows:

$$\frac{t}{M_t - M_o} = K_1 + K_2 t \qquad (9)$$

A plot of $t/(M_t\text{-}M_o)$ versus time t gives a straight line with K_1 as the ordinate intercept and K_2 as the line's gradient. The rehydration is long enough, and the equilibrium moisture content (M_e) is calculated as $M_e = M_o + 1/K_2$

2.5.6 Arrhenius model

The soaking temperature dependency on the hydration rate of dried mud eel was evaluated using the Arrhenius kinetics model (Saeid *et al.,* 2016). The Arrhenius equation can be written as:

$$k = k_o e^{-EaRT} \qquad (10)$$

Rearranging the equation (5) as follows:

$$\ln k = \ln k_o \frac{E_a}{RT} \qquad (11)$$

Where k is the hydration rate constant (min^{-1}), E_a is the activation energy, R is the universal gas constant (8.314 kJ/mol°K), T is the absolute temperature (°K), and k_o is a constant with the same units as the hydration constant. The activation energy was computed using the graph's slope of -Ea/R and the plot of ln k vs. 1/T.

2.5.7 Water rehydration capacity determination

One of the most crucial physical metrics to evaluate the eating quality of dried fish products is water reconstitution, measured as a percentage of water reconstitution under specified conditions. The water rehydration capacity of the dried sample was determined according to the method reported by Rana *et al*. (2022) with slight modifications. In this process, 5 g of dried mud eel samples were used for each experiment. The samples wrapped with a nylon net were soaked in water at 28°C, 40°C, and 60°C. For each temperature, samples were kept in the hot water bath chamber for 15, 30, 45, and 60 mins (NANBEI, model: DZKW-D-6, China). After the allotted time had passed, the dried mud eel was transferred to the strainer, surplus water was drained using tissue paper, and the mixture was weighed using an electric balance (P-scale, model: PS. P13100g, Taiwan). The weight gain was interpreted as the volume of water absorbed. Each sample was examined three times, and the moisture percentage was calculated dryly (%db). The amount of moisture that the mud eel fish flesh gained or absorbed was expressed as a percentage and computed using the method below:

$$\text{Water reconstitution } (\%) = \frac{W_r - W_i}{W_i} \times 100 \qquad (12)$$

Where W_i = initial weight of the dry fish, Wr = weight of the dry fish after water absorption.

2.6 Sensory evaluation

Samples of dried mud eel were tested for their sensory qualities. A panel of thirty-four semi-trained participants, consisting of an equal number of male and female non-smokers between the ages of 23 and 24, was selected from the university student population. The panelists were given the samples at random. Dried mud eel samples were evaluated on an organoleptic scale of nine points (9-like highly to 1-dislike extremely) for color, taste, texture, and overall acceptability, as reported by Hossin *et al.* (2021).

2.7 Statistical analysis

There were three replicates of each experiment. R's statistical program was used to analyze the data, displayed as mean ± standard deviation (SD) (windows version 2.13.1). Data were analyzed using analysis of variance (ANOVA) and followed by Duncan's Multiple Range Test (DMRT) to determine whether there was a

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difference in mean values that were significant at the level of (p<0.05).

3. Results and discussion

3.1 Proximate composition

The proximate composition of dried mud eel obtained after treating different drying methods is shown in Table 1. The moisture content of dried mud eel has been reduced with thermal treatment, which is reflected in the raw mud eel. The moisture content was in the range of 10.54 to 20.73% from the table. The highest moisture content was found in the sun-dried sample treated with salt solution and the lowest in the oven-drying sample. The obtained values of this study agreed with the work of Azam *et al.* (2003), who reported that dried fish contained moisture content ranging from 18.23 to 23.61%. The moisture content of different dried fish species ranged from 15.66-35.50% (Rana *et al.,* 2020), comparable with these findings. Wood-smoked dried tilapia contained 48.24% moisture, as reported by Lelwela *et al.* (2021), which was much higher than this investigation. Typically, the sun-dried fishes had an average of 10 to 20% moisture (Flowra *et al.,* 2012). Akinneye *et al.* (2010) reported that *Heterotis niloticus* had the highest (16.42%) moisture content, while minor moisture content (9.27%) was obtained from oven-dried and sun-dried *Sardinella* sp. Moisture content varied in the dried fish might be the effect of the different drying methods (Rana *et al.,* 2020).

The protein content of dried mud eel varied from 59.47 to 75.80%, with the highest found in the sun-dried sample and the lowest in a salt-treated sun-dried sample. The results were highest compared to Akinneye *et al.* (2010), who reported different dried fish species using sun drying and oven drying and showed protein content ranging from 22.47 to 51.06% (Akinneye *et al.,* 2010). Lelwela *et al.* (2021) found that smoke-dried fish contain 28.6% protein. The protein content of dried fish can vary depending on the species, according to Rana *et al.* (2020). Rasul *et al.* (2018) found that dried churi contained 65.78% and solar-dried silver carp with 68.41% protein, respectively, comparable with this work. Typically, dried fish contains up to 80% protein content (Sultana *et al.,* 2011). The lowest moisture can be attributed to the highest protein concentration in the dried sample, and a similar observation was reported by Weber *et al.* (2008).

The lipid content of dried mud eel obtained from different thermal treatments was 2.08 to 3.84%. The lipid content was higher in the sun-dried sample and lowered in the smoke-dried sample. The dried silver carp obtained using the different drying methods was between 6.21 and 7.04% (Rasul *et al.,* 2018), higher than the observed values of this study. The dried *Channa punctatus* contained 1.91 and 2.31% lipid content (Flowra *et al.,* 2012), lower than these findings. The lipid content of small dried fish species varied from 4.20% to 13.03% (Rana *et al.,* 2020). The loss of moisture content from dried fish was the core contributor to lipid increment. The same trend was followed by all dried samples except smoke-dried, which was found to be lower and significantly different (p<0.05) from other samples.

Furthermore, the ash content of dried mud eel was higher in the smoke-dried sample at 17.44% and lowest found at 11.53% in the oven-dried sample. Lelwela *et al.* (2021) found similar results and reported that smoke-dried wood fish had 11.89% ash (Lelwela *et al.,* 2021). Rana *et al.* (2020) investigated that the ash content of different dried fish species ranged from 5.28% to 18.60%; this was in close agreement with the investigation of this study (Rana *et al.,* 2020). Islam *et al.* (2013) found that the ash content of dried Mola and Taki ranged from 20.14% to 24.40%, which was lower than the findings of this study. However, Smoke drying enhanced the ash content compared to other samples by reducing moisture content. A similar observation was found by Yanar *et al.* (2006). It was observed that salt treatment enhanced the ash content in the samples except for the smoke-dried sample (Yanar *et al.,* 2006).

Table 1. Physicochemical characteristics of dried mud eel obtained from different drying methods.

Drying methods	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)
Raw	77.85	18.34	2.53	1.24
Sun dry	17.21±0.68^{b}	75.80±0.18^{a}	3.84±0.12^{a}	11.71±0.32^{c}
Oven dry	10.54±0.80^{d}	74.90±0.94^{a}	3.66±0.21^{a}	11.53±0.20^{c}
Smoke dry	12.19±2.73^{cd}	67.01±1.75^{c}	2.08±0.03^{b}	17.44±1.08^{a}
Sun dry+10% salt	20.73±1.22^{a}	59.47±1.18^{e}	2.91±0.84^{ab}	14.62±1.12^{b}
Oven dry+10% salt	14.96±2.45^{bc}	64.20±0.97^{d}	3.12±0.41^{a}	15.72±0.87^{ab}
Smoke dry+10% salt	12.16±1.82^{cd}	69.23±1.52^{b}	2.99±0.82^{ab}	14.85±1.63^{b}

Values are presented as mean±SD. Values with different superscript within the same column are statistically significantly different (P≤0.05).

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3.2 Water absorption capacity

The water absorption capacity of dried mud eel was obtained by the different thermal treatments using different soaking temperatures at 28°C, 45°C, and 60°C, illustrated in Figure 1 (A-C). The figure shows that the initial rate of water uptake increases as the soaking time increases for all samples. The same trend was followed by water absorption increases when water temperature increases (Figure 1 A-C). This suggested that rapid rehydration happened when the water temperature was high. Similar findings were found by Sevim *et al.* (2023) by rehydrating the blue mussels (*Mytilus edulis*). Except for 28°C, when the sun-dried sample had the most elevated water uptake, it was found that the oven-dried sample had the maximum water absorption capacity at all temperatures in this investigation. Table 2 presents an overview of the linear regression models fitted to all data at various rehydration temperatures for all drying techniques. The experimental results at all of the calculated temperatures were well fitted to Peleg's equation by the high coefficients of determination (R^2 = 0.90) in every case.

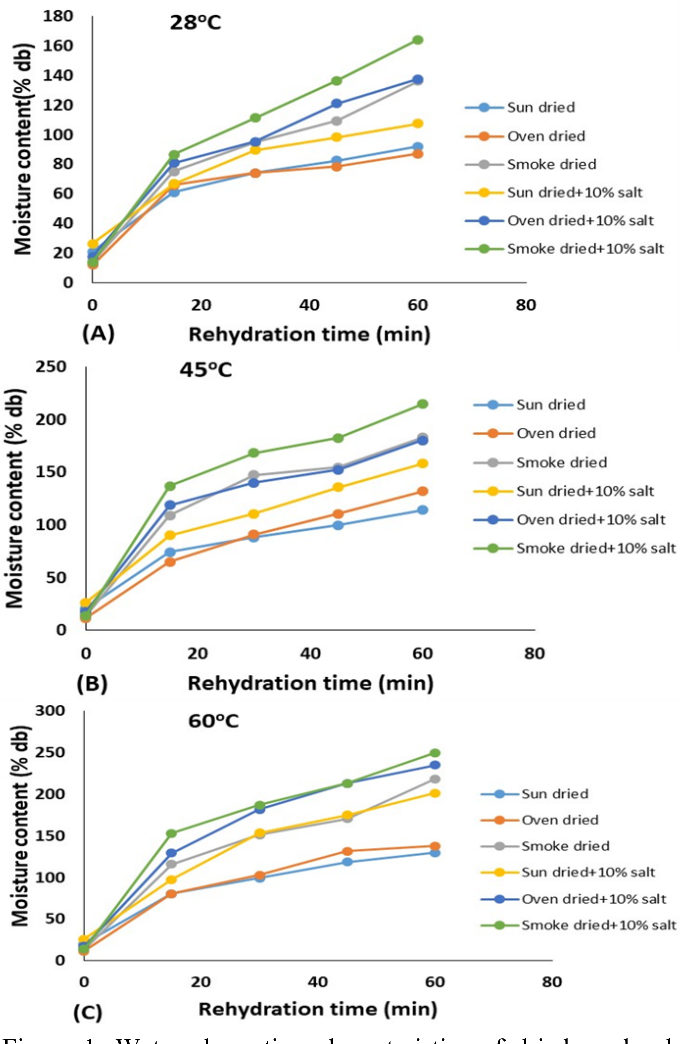

Figure 1. Water absorption characteristics of dried mud eel soaking under different temperatures (A) 28°C, (B) 45°C and (C) 60°C.

3.2 Linear regression model fitting

Table 2 displays the linear regression models that were fitted [$t/(M_t-M_o)$ versus t] along with Figure 2 (A-C) to the data of dried mud eel that had been hydrated at various hydration temperatures. The table demonstrates that, with the exception of oven-dried, smoke-dried, and salt-treated oven-dried samples, Peleg's constant K_1 dropped linearly (R^2>0.90) as the hydration temperature increased from 28°C to 60°C for all dry mud eel samples. This suggests that the initial water absorption rate has increased in line with this (Turhan *et al.,* 2002). This K_1 is correlated with the rate of mass transfer; for instance, the higher the initial rate of water absorption, the lower the K_1. The favorable impact of higher temperature on the water rate is shown by its temperature sensitivity (Tunde-Akintunde, 2010). A comparable study has been reported by Maharaj and Sankat (2000) and Tunde-Akintunde (2010). For sun-dried, salt-treated sun-dried, and salt-treated smoke-dried samples, it was found that the temperature sensitivity was most apparent

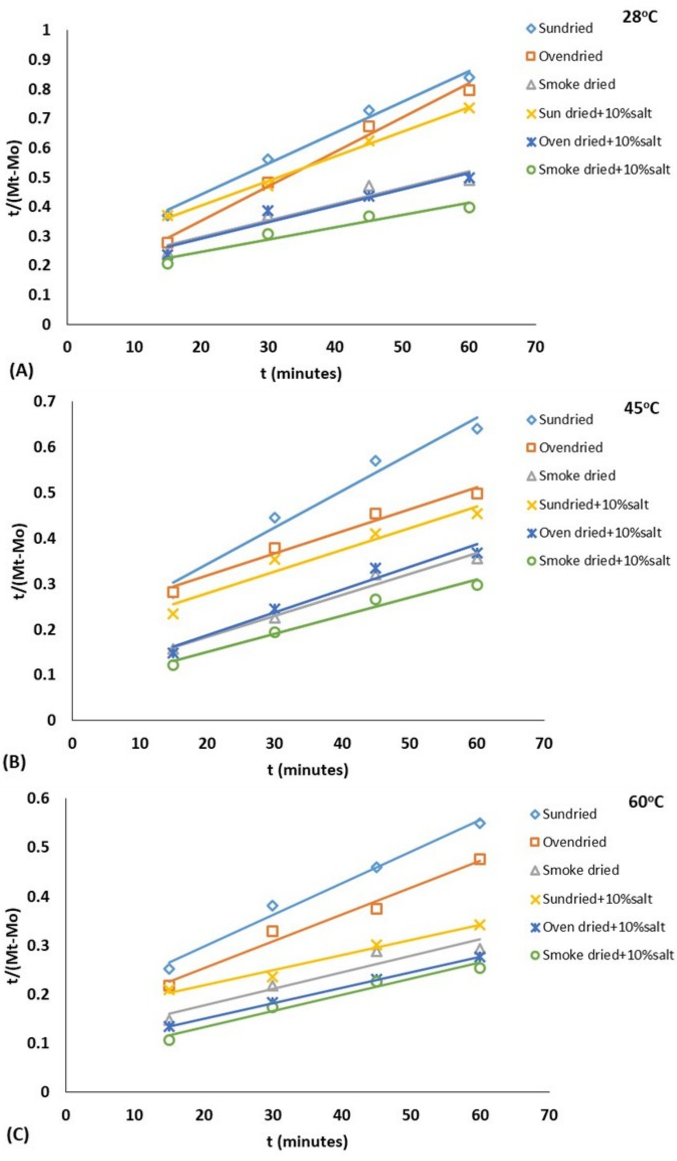

Figure 2. Linear regression model for dried mud eel hydrated at (A) 28°C, (B) 45°C and (C) 60°C.

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Table 2. Linear regression models fitted $t/(M_t-M_o)$ versus t and Peleg's constant K_1 as well as equilibrium moisture content for dried mud eel hydrated at 28°C, 45°C and 60°C.

Drying method	Temperature (°C)	Estimated slop K_2 (% mc db)$^{-1}$	K_1	Predicted equilibrium moisture content (% mc db)	$1/K_1$	R^2
Sun drying	28	0.0105	0.2319	116.02	4.31	0.98
	45	0.0081	0.1823	144.25	5.49	0.97
	60	0.0065	0.1675	174.64	5.97	0.98
Oven drying	28	0.0117	0.1190	97.25	8.40	0.98
	45	0.0049	0.2217	215.86	4.51	0.97
	60	0.0055	0.1431	193.60	6.99	0.97
Smoke drying	28	0.0056	0.1860	192.53	5.38	0.92
	45	0.0046	0.0927	231.35	10.79	0.97
	60	0.0034	0.1000	308.08	10.00	0.91
Sun dry+10% salt	28	0.0084	0.2377	145.22	4.21	0.99
	45	0.0048	0.1847	234.50	5.41	0.94
	60	0.0031	0.1568	348.75	6.38	0.97
Oven dry+10% salt	28	0.0056	0.1802	196.23	5.55	0.93
	45	0.0050	0.0868	217.66	11.52	0.96
	60	0.0032	0.0874	330.16	11.44	0.99
Smoke dry+10% salt	28	0.0042	0.1611	251.97	6.21	0.94
	45	0.0040	0.0697	263.87	14.35	0.97
	60	0.0033	0.0665	316.90	15.04	0.97

Values are presented as mean±SD. Values with different superscript within the same column are statistically significantly different (P≤0.05).

at a soaking water temperature of 60°C, where the K_1 value was the lowest (Table 2). At a soaking temperature of 60°C, the initial water absorption (hydration) rate, as evaluated by $1/K_1$ weight, was maximum, consistent with the hydration curves of Figure 1. (A-C). In the oven drying sample, Peleg's constant K_1 initially increased and then gradually fell, which was nonlinear ($R^2 = 0.22$) with temperature, as evidenced by the Arrhenius model data not shown. K_1's relationship to temperature sometimes varied nonlinearly. All chickpea cultivars, with the exception of Semsen and three field pea cultivars, fit a nonlinear regression model better than a linear regression model between 5 and 42°C, according to Hung *et al.* (1993), who published K_1 values. The sample with the greatest starting hydration rate further supported the smoke-dried and salt-treated oven-dried sample's sensitivity to a temperature of 45°C. However, the initial water uptake rate for the oven-dried sample was higher than the sun-dried sample for all soaking temperatures, with the exception of 45°C, as shown by $1/K_1$ values; the highest value discovered was 8.40 at 28°C. This may be caused by the sample reflecting the least amount of moisture, a similar phenomenon to that described by Hung *et al.* (1993).

The maximum water absorption capacity is correlated with Peleg's capacity constant K_2; the lower the K_2, the greater the water absorption capacity. As a result, with the exception of oven-dried samples, Peleg's capacity constant K_2 dropped for each analyzed dry sample as the soaking water's temperature rose. The hazel kernel and full Hazelnut, Acha, Pearl millet grains, and Hungry rice revealed similar results (Lopez *et al.,* 1995; Tunde-Akintunde, 2010). Both reports existed in the literature, either temperature or no effects on food materials' water absorption capacity (K_2). This depends on the type of material and if soluble solids loss during soaking is considered in calculating the moisture content of samples (Agarry *et al.,* 2014). Many researchers have reported using Peleg's model to show that there are no temperature effects on K_2 in their water absorption studies. Studies by Turhan *et al.* (2002) reported that chickpea's water absorption capacity (K_2) increased as the soaking temperature increased.

According to Abu-Ghannam and McKenna (1997), the equilibrium moisture content is determined by the constant K_2. The levels of K_2 in this investigation did not correlate perfectly with temperature. At 28°C, the samples that had been sun, oven, smoked, and smoke-dried and treated with salt had the highest K_2 values. This suggests that the maximum water capacity of dried mud eel was found to be lowest at 28°C. Peleg's constants K_2 were used to calculate the equilibrium moisture content. It was observed that the equilibrium moisture content was found to be highest in the salt-treated dried samples. This indicates that pretreatment with salt offers a protective effect on the tissue damage

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of mud eel during drying. A similar agreement was reported by Tadesse *et al.* (2016) for dried and rehydrated carrot samples.

3.3 Sensory analysis

Figure 3 illustrates the sensory analysis of the dried mud eel obtained by different drying methods. The sensory characteristics of dried mud eel were evaluated in color, flavor, texture, and overall acceptability and obtained organoleptic scores for color (7.06-8.11), flavor (6.85-7.65), texture (6.85-7.76), and overall acceptability (7.29-8.09). The first impression of the quality and acceptability of any food sample is judged by its color. The highest score, 8.11 for color, was found in (smoked dried sample + 10% salt). The flavor has a significant impact on product acceptability. The pleasant flavor of sun-dried mud eel was reflected as the highest score. The texture of the sun-dried sample retained the maximum organoleptic values compared to other samples. The overall acceptability values were most elevated in the sun-dried sample. From Figure 3, it can be observed that salt treatment did not change the sensory score for all samples except the smoke-dried sample, which improved significantly. Overall, the sun-dried mud eel had the better result for all sensory parameters except the color, which was found higher in smoke-dried mud eel, which was non-significant (p<0.05) with sun-dried samples.

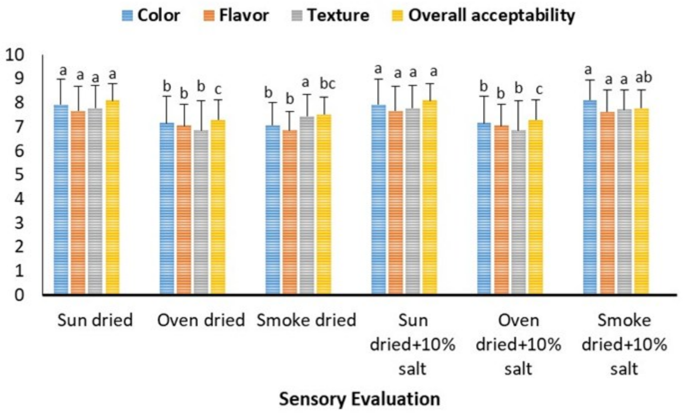

Figure 3. Sensory characteristics of dried mud eel obtained by different drying methods.

3.4 Activation energy

Table 3 shows the kinetics data using the Arrhenius model for dried mud eel obtained by different drying methods, soaked at 28°C, 45°C and 60°C. The Arrhenius equation sufficiently described the temperature effect on the hydration rate, as the regression coefficient reached more than 0.82, except the oven-dried sample was 0.22. The activation energy (E_a) was calculated from the slope (ln k vs 1/T) of the plot and ranged from 8.08 to 25.99 ($KJmol^{-1}$) for all samples, with salt-treated smoked dried mud eel having a greater activation energy and oven-dried mud eel having a lower activation energy. This is in close agreement with the work of Komolafe *et al.* (2018), who reported that the tilapia fish had an activation energy (E_a) of 23.79 $KJmol^{-1}$. Ortiz *et al.* (2013) reported that the activation energy of 24.57 $KJmol^{-1}$ for Atlantic salmon fillets dried at 40–60°C. Guan *et al.* (2013) found an activation energy of 17.66 $KJmol^{-1}$ for tilapia fillets dried at 35–55°C. Nevertheless, a lower value of activation energy results in a faster moisture absorption rate. Tunde-Akintunde (2010) reported a similar observation.

Table 3. Arrhenius kinetics data for the soaking temperature dependency on the hydration rate of dried mud eel at 28°C, 45°C and 60°C.

Drying method	Temperature (°C)	K_1	R^2	E_a ($KJmol^{-1}$)
Sun drying	28	0.2319	0.99	9.16
	45	0.1823		
	60	0.1675		
Oven drying	28	0.1190	0.22	8.08
	45	0.2217		
	60	0.1431		
Smoke drying	28	0.1860	0.82	18.88
	45	0.0927		
	60	0.1000		
Sun dry+10% salt	28	0.2377	0.99	11.38
	45	0.1847		
	60	0.1568		
Oven dry+10% salt	28	0.1802	0.89	21.53
	45	0.0868		
	60	0.0874		
Smoke dry+10% salt	28	0.1611	0.92	25.99
	45	0.0697		
	60	0.0665		

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4. Conclusion

This study demonstrated that different drying methods, such as sun drying, oven drying, and smoke drying, with and without salt pretreatment, significantly influence the proximate composition, sensory qualities, and rehydration characteristics of mud eel (*Monopterus cuchia*). Sun-dried mud eel showed the most favorable sensory qualities, except for color, which was preferred in smoke-dried samples. Salt pretreatment enhanced tissue integrity, resulting in higher equilibrium moisture content and better structural stability, as indicated by rehydration modeling using Peleg's model, which proved highly applicable ($R^2 > 0.90$). These findings suggest that sun drying, followed by oven drying and salt-treated smoke drying, provides effective preservation methods for mud eel while retaining its nutritional quality and sensory acceptability. This research contributes to establishing reliable drying practices that could enhance the marketability of dried mud eel domestically and internationally by ensuring extended shelf life and maintained quality. Future research could further optimize these drying methods and explore the underlying mechanisms of salt pretreatment in tissue preservation.

Conflict of interest

The authors declare no conflict of interest.

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