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Effects of Brine Concentration and Drying Method on Proximate Composition, Calcium Retention, Lipid Oxidation, Spoilage Indicators, and Sensory Quality of Dried Bilih Fish (Mystacoleucus padangensis) from Lake Singkarak, West Sumatra

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Abstract

Bilih (Mystacoleucus padangensis) is a small cyprinid fish that supports an artisanal fishery in Lake Singkarak, West Sumatra, Indonesia, and is commonly preserved by salting and sun drying. Because bilih is consumed whole, including the soft bones, it is a potentially valuable source of dietary calcium. However, the traditional process is poorly standardized: salt levels are set by experience, and open-air drying under humid tropical conditions is slow and exposes the product to oxidation and microbial contamination. This study evaluated the effects of three brine concentrations (5%, 10%, and 15% w/v NaCl) and two drying methods (sun drying and cabinet drying at 55°C) on the proximate composition, water activity (aw), calcium content, lipid oxidation (TBARS), total volatile basic nitrogen (TVB-N), total plate count, and sensory acceptability of dried bilih. A 3 × 2 factorial Completely Randomized Design with three replicates was used, and quality indicators were monitored during 30 days of storage at ambient temperature (28 ± 2°C). Both factors significantly affected all measured parameters ($p < 0.001$). Cabinet drying produced lower moisture (14.9–17.8%) and aw (0.64–0.71) than sun drying (18.1–21.4%; aw 0.71–0.78). Increasing brine concentration lowered aw and slowed spoilage-related changes in TVB-N and microbial counts, but raised lipid oxidation: TBARS at day 0 was 53% higher at 15% than at 5% brine within each drying method. Cabinet drying reduced TBARS by 37–39% relative to sun drying at all salt levels. After 30 days, only the cabinet-dried samples remained below a TVB-N value of 30 mg N/100 g at every salt level. Salt uptake diluted protein and calcium on a dry-weight basis (calcium 1,276–1,409 mg/100 g), although the products remained rich in both. Sensory acceptability was highest for 10% brine with cabinet drying (overall score 4.3/5.0), which also had the best combined rank across aw, TBARS, TVB-N, and sensory criteria. These findings support salting in 10% brine followed by cabinet drying at 55°C as a practical improvement over traditional practice for bilih processors around Lake Singkarak.

Keywords: Bilih fish; Mystacoleucus padangensis; Lake Singkarak; salting; drying; lipid oxidation; TVB-N; calcium; water activity; traditional fish processing

Introduction

Inland capture fisheries and small-scale aquaculture make an important contribution to food and nutrition security in many tropical countries, and small indigenous fish in particular are consumed regularly by rural households [1]. In West Sumatra, the volcanic and tectonic lakes of the Barisan highlands support artisanal fisheries that supply local markets and cultural food traditions. Among these, bilih (Mystacoleucus padangensis Bleeker, 1852; family Cyprinidae) is a small silver-bodied fish, generally 6–9 cm in length, that is native to Lake Singkarak and its tributaries and is harvested by local fishers for sale fresh, fried, or dried [2].

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Small fish that are eaten whole are nutritionally distinctive. Because the head, viscera, and soft bones are consumed together with the flesh, they supply protein, essential fatty acids, iron, zinc, and notably calcium in a single food [3]. Controlled human studies have shown that calcium from whole small fish is absorbed about as well as calcium from milk, which makes such fish a practical calcium source where dairy intake is low [4, 5]. Dried bilih therefore has real potential as an affordable nutrient-dense food, provided that its quality and safety can be assured.

Salting followed by drying is the oldest and most widespread way of preserving fish in the tropics. Salt draws water out of the tissue by osmosis, lowers water activity (aw), and inhibits many spoilage and pathogenic bacteria, while drying removes further moisture and extends shelf life [6, 7]. In practice, bilih processors around Lake Singkarak salt the fish by experience, without fixed brine strength or soaking time, and dry them in the open air on bamboo mats. Under the high relative humidity of the West Sumatran highlands, sun drying can take two days or more, and the fish are exposed to dust, insects, ultraviolet radiation, and rain, all of which compromise product consistency.

These practices create two competing quality risks. First, if the final aw remains above about 0.70, xerophilic molds and halotolerant bacteria can grow during storage, and proteolytic spoilage continues, raising total volatile basic nitrogen (TVB-N) [8, 9]. Second, salt is not chemically neutral toward lipids: at higher concentrations it has repeatedly been reported to accelerate lipid oxidation in fish, and the polyunsaturated lipids of fish muscle are already highly susceptible to oxidative rancidity [10, 11]. A processor who increases salt to improve microbial safety may therefore worsen oxidative quality, and vice versa. Quantitative data on how brine concentration and drying method jointly shape these opposing outcomes for bilih are lacking.

The objectives of this study were therefore: (i) to determine the proximate composition and calcium content of dried bilih produced with three brine concentrations and two drying methods; (ii) to evaluate water activity, lipid oxidation, TVB-N, and microbial load during 30 days of ambient storage; (iii) to assess sensory acceptability; and (iv) to identify the combination of brine concentration and drying method that gives the best overall compromise between safety, nutritional value, and consumer acceptance.

Literature Review

2.1. Small Whole Fish as Nutrient-Dense Foods

Fish muscle typically contains 15–20% protein on a wet basis, with an amino acid profile rich in lysine and sulfur-containing amino acids that complements cereal-based diets [6]. In small fish eaten whole, the skeleton adds substantial calcium and phosphorus, and the viscera and skin contribute iron, zinc, and vitamins [3]. Larsen et al. reported that whole small fish provided calcium of comparable bioavailability to milk in human volunteers [4], a finding supported by balance studies using soft-boned fish [5]. In addition, fish lipids contain long-chain n-3 polyunsaturated fatty acids associated with cardiovascular and neurological benefits [22]. These nutritional attributes, however, are exactly the components most exposed to loss or degradation during preservation, which is why process optimization matters.

2.2. Salting, Water Activity, and Moisture Removal

During salting, brine penetrates the tissue while water leaves it; salt uptake and water loss both increase with brine concentration and contact time. The resulting reduction in aw is the main reason salted fish resists bacterial spoilage, because most spoilage bacteria are inhibited below an aw of about 0.90, and most halophilic and xerophilic organisms below about 0.75 [8, 23]. Salt also solubilizes myofibrillar proteins,

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changes water-holding capacity, and modifies texture [23]. Subsequent drying is governed by external conditions: temperature, air velocity, and humidity determine the rate of moisture removal, with controlled hot-air drying generally faster and more uniform than open sun drying in humid climates [7, 25].

2.3. Lipid Oxidation and Protein Changes in Salted Dried Fish

Lipid oxidation in fish proceeds through free radical chain reactions that generate hydroperoxides and secondary products such as malondialdehyde, measured as thiobarbituric acid reactive substances (TBARS). Several factors accelerate it in salted products, including the pro-oxidant effect of sodium chloride at high concentration, exposure to oxygen and light during drying, and the presence of heme and non-heme iron in muscle [10, 11]. Oxidation also affects proteins, causing carbonylation, cross-linking, and loss of solubility, which can harden texture and reduce sensory quality [21]. Long, slow drying under sunlight is expected to aggravate these changes compared with shorter drying in a closed cabinet [11, 24].

2.4. Spoilage Indicators: TVB-N and Microbial Load

TVB-N, which includes ammonia and volatile amines produced by bacterial and endogenous enzymatic deamination, is widely used as a chemical indicator of freshness and spoilage in fish [12, 19]. European regulation sets TVB-N limits of 25–35 mg N/100 g depending on the fish category, and these values are commonly used as indicative acceptability thresholds for other fish products [16]. Total plate count complements TVB-N by reflecting the viable bacterial load; for dried salted fish, both indicators tend to rise during storage when aw is permissive, and rise more slowly when aw and salt content are inhibitory [12, 13].

Materials and Metods

3.1. Raw Material

Fresh bilih were purchased directly from fishers at a landing site on the shore of Lake Singkarak, West Sumatra, in the early morning and transported to the laboratory within 3 hours in insulated boxes with crushed ice at a fish-to-ice ratio of 1:1. Fish were sorted for uniform size (length 7.4 ± 0.6 cm; weight 5.1 ± 0.7 g), rinsed with chilled potable water, and processed immediately. A representative subsample of raw fish was retained for baseline analysis. All reagents were of analytical grade.

3.2. Salting and Drying Treatments

Whole, ungutted fish were immersed in brine at 5%, 10%, or 15% (w/v) NaCl, at a fish-to-brine ratio of 1:2 (w/w), for 30 minutes at 25 ± 1°C, then drained for 10 minutes. Each salted batch was divided into two drying treatments: (SD) sun drying on clean bamboo trays covered with fine nylon mesh for two days (approximately 8 hours per day; ambient 30–34°C, relative humidity 65–78%), with the product brought indoors overnight; and (CD) drying in a forced-air cabinet dryer at 55 ± 1°C for 6 hours. The six treatment combinations are coded S5-SD, S5-CD, S10-SD, S10-CD, S15-SD, and S15-CD. After cooling to room temperature, 100 g portions were sealed in polypropylene bags (50 µm) and stored at 28 ± 2°C. Analyses were carried out on day 0 (immediately after drying) and day 30.

3.3. Proximate Composition, Salt, aw, and Calcium

Moisture, protein (Kjeldahl, N × 6.25), crude fat (Soxhlet extraction), and ash were determined according to standard AOAC methods [13]. Salt content was determined by argentometric (Mohr) titration of chloride and expressed as NaCl percentage of the wet product. Water activity was measured at 25°C with a calibrated dew-point water activity meter. Calcium was determined by inductively coupled plasma optical emission spectrometry after microwave-assisted acid digestion and expressed per 100 g dry weight.

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3.4. Lipid Oxidation and TVB-N

Lipid oxidation was assessed by the TBARS method of Vyncke using trichloroacetic acid extracts [14]; absorbance was read at 532 nm and results were expressed as mg malondialdehyde (MDA) per kg of sample, calculated from a 1,1,3,3-tetraethoxypropane standard curve. TVB-N was determined by the Conway microdiffusion method [15], with results expressed as mg N/100 g of sample.

3.5. Microbiological Analysis

Ten grams of homogenized sample were suspended in 90 mL of sterile 0.85% NaCl containing 0.1% peptone, and serial dilutions were pour-plated on Plate Count Agar supplemented with 3% NaCl to permit growth of halotolerant bacteria. Plates were incubated at 30°C for 72 hours, and results were expressed as log CFU/g.

3.6. Sensory Evaluation

Thirty semi-trained panelists (aged 20–45 years, regular consumers of dried fish) evaluated day-0 samples, which were fried briefly in refined palm oil under standardized conditions to reflect normal consumption. Appearance, aroma, saltiness, texture (crispness), and overall acceptability were scored on a five-point hedonic scale (1 = dislike extremely; 5 = like extremely) following standard practice [17]. Samples were coded with random three-digit numbers and presented in randomized order, with water and unsalted crackers provided between samples. Panelists gave informed consent.

3.7. Experimental Design and Statistical Analysis

A 3 × 2 factorial Completely Randomized Design (three brine concentrations × two drying methods) with three replicates was applied (18 experimental units). Data are presented as mean ± standard deviation. Two-way analysis of variance was used to test main effects and the interaction, followed by Duncan's multiple range test at $p < 0.05$ [18] using SPSS 27.0. Pearson correlation coefficients were computed among NaCl content, aw, TBARS, TVB-N, and microbial count. Treatments were also ranked on aw, day-30 TBARS, day-30 TVB-N, and overall sensory score, and rank sums were compared to identify the best overall treatment.

Results and Discussion

4.1. Composition of Fresh Bilih

The baseline composition of fresh bilih is shown in Table 1. The fish contained 76.8% moisture, 17.2% protein, and 3.9% fat on a wet basis, which places bilih in the lean-to-medium fat category and is consistent with the general composition range reported for small freshwater fish [6]. Because the fish were analyzed whole, the calcium content of 340 mg/100 g wet weight (about 1,466 mg/100 g on a dry basis) reflects the contribution of the skeleton and is high relative to fillet-based values, which supports the use of bilih as a calcium source [3, 4].

Table 1. Baseline composition of fresh whole bilih fish (Mystacoleucus padangensis) from Lake Singkarak (mean ± SD, n = 3).

Parameter	Value	Basis
Moisture	76.8 ± 0.5	% wet weight
Protein	17.2 ± 0.3	% wet weight
Fat	3.9 ± 0.2	% wet weight
Ash	2.6 ± 0.1	% wet weight
Calcium	340 ± 12	mg/100 g wet weight
TBARS	0.31 ± 0.03	mg MDA/kg

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TVB-N	11.8 ± 0.5	mg N/100 g
Total plate count	4.6 ± 0.2	log CFU/g

TBARS = thiobarbituric acid reactive substances; MDA = malondialdehyde; TVB-N = total volatile basic nitrogen.

4.2. Moisture, Water Activity, and Salt Uptake

Both brine concentration and drying method significantly affected moisture, aw, and salt content ($p < 0.001$; Table 2). Cabinet-dried fish had 3.2–3.6 percentage points less moisture than sun-dried fish at every salt level, and aw fell from 0.78 (S5-SD) to 0.64 (S15-CD). Salt content in the product increased almost linearly with brine concentration, from 3.9–4.2% at 5% brine to 10.6–11.3% at 15% brine; cabinet-dried samples showed slightly higher salt percentages because of the greater moisture loss.

Table 2. Moisture, water activity, salt, protein, fat, and calcium of dried bilih (mean ± SD, n = 3).

Parameter	S5-SD	S5-CD	S10-SD	S10-CD	S15-SD	S15-CD
Moisture (%)	21.4 ± 0.6	17.8 ± 0.5	19.6 ± 0.5	16.2 ± 0.4	18.1 ± 0.5	14.9 ± 0.4
Water activity (aw)	0.78 ± 0.01	0.71 ± 0.01	0.74 ± 0.01	0.67 ± 0.01	0.71 ± 0.01	0.64 ± 0.01
NaCl (% wet basis)	3.9 ± 0.2	4.2 ± 0.2	7.3 ± 0.3	7.8 ± 0.3	10.6 ± 0.4	11.3 ± 0.4
Protein (% dry weight)	69.4 ± 0.8	70.1 ± 0.8	67.1 ± 0.8	67.5 ± 0.7	64.2 ± 0.7	64.8 ± 0.7
Fat (% dry weight)	15.9 ± 0.4	16.0 ± 0.4	15.2 ± 0.4	15.4 ± 0.4	14.6 ± 0.3	14.8 ± 0.3
Calcium (mg/100 g dry weight)	1,402 ± 28	1,409 ± 27	1,334 ± 26	1,339 ± 25	1,276 ± 24	1,283 ± 24

S5, S10, S15 = 5%, 10%, 15% brine; SD = sun drying; CD = cabinet drying at 55°C. Main effects of brine concentration and drying method significant for moisture, aw, and NaCl ($p < 0.001$).

An aw below 0.70 is generally needed to prevent growth of most xerophilic molds, and values of 0.75–0.80 still allow growth of some halotolerant bacteria and molds over weeks of storage [8, 23]. Only the S10-CD and S15-CD products (aw 0.67 and 0.64) were clearly below 0.70; S5-CD and S15-SD were borderline at 0.71, and S5-SD (aw 0.78) was the least stable. This shows that the choice of drying method has a decisive effect on microbial stability that salt alone cannot fully replace: the 10% brine with sun drying (aw 0.74) was less well protected than 5% brine with cabinet drying (aw 0.71).

4.3. Protein and Calcium Retention

On a dry-weight basis, protein ranged from 64.2% to 70.1% and calcium from 1,276 to 1,409 mg/100 g (Table 2). Both declined as brine concentration rose, but the declines were close to what would be expected from simple dilution by absorbed salt. For example, the 15% brine products contained about 13% salt on a dry basis, and their protein (64.2–64.8%) and calcium values were about 7–9% lower than those of the lightly salted products, close to the additional dilution expected from the higher salt content (about 13% versus 5% on a dry basis); drying method had only a small effect on either component. This indicates that the nitrogen and mineral fractions were retained rather than lost, in line with studies showing that the mineral content of fish is largely conserved during processing and that composition changes mainly reflect moisture and salt redistribution [20].

From a nutritional standpoint, a 20 g portion of S10-CD product (about 16.8 g of dry matter) would supply roughly 225 mg of calcium on the basis of Table 2, which is useful relative to typical adult requirements, though the actual contribution depends on how much is eaten and on bioavailability [4, 5]. At the same

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time, a 20 g portion would contain around 1.5 g of salt, so the calcium benefit has to be weighed against sodium intake, and the lowest brine concentration that achieves safety is preferable from a public health standpoint.

4.4. Lipid Oxidation

Lipid oxidation was strongly affected by both factors, and the salt × drying interaction was significant ($p = 0.018$; Table 3). At day 0, TBARS increased with brine concentration: within each drying method, the 15% brine products had TBARS values 53% higher than the 5% brine products. This agrees with reports that sodium chloride promotes oxidation in fish muscle, possibly by displacing iron from binding sites and by disrupting membrane structure [10, 11]. Cabinet drying reduced TBARS by 37–39% compared with sun drying at all salt levels, and the absolute benefit of cabinet drying was larger at higher salt (0.67 mg MDA/kg at 15% brine versus 0.44 at 5%), which explains the interaction.

Table 3. TBARS values (mg MDA/kg) of dried bilih at day 0 and after 30 days of ambient storage (mean ± SD, n = 3).

Storage	S5-SD	S5-CD	S10-SD	S10-CD	S15-SD	S15-CD
Day 0	1.12 ± 0.06	0.68 ± 0.04	1.34 ± 0.07	0.82 ± 0.05	1.71 ± 0.08	1.04 ± 0.06
Day 30	2.46 ± 0.11	1.52 ± 0.08	2.88 ± 0.12	1.78 ± 0.09	3.52 ± 0.15	2.21 ± 0.10

Fresh raw bilih = 0.31 ± 0.03 mg MDA/kg. Values above about 2 mg MDA/kg are often associated with perceptible rancidity in fish products and are given here as an indicative reference only.

During 30 days of storage, TBARS roughly doubled in all treatments. The sun-dried products exceeded 2 mg MDA/kg at all salt levels, whereas S5-CD (1.52) and S10-CD (1.78) remained below this indicative reference and S15-CD (2.21) marginally exceeded it. The slower oxidation of cabinet-dried fish is consistent with its shorter exposure to oxygen, light, and warm ambient temperatures during drying, and with the lower residual moisture, which reduces mobility of pro-oxidants [11, 24]. The data therefore illustrate the trade-off noted in the introduction: raising salt improves microbial protection, but it should not be raised beyond what is necessary because oxidation worsens.

4.5. TVB-N and Microbial Load

TVB-N and total plate count behaved in the opposite direction to TBARS with respect to salt (Table 4). At day 0, TVB-N was already lower in cabinet-dried fish (15.6–19.8 mg N/100 g) than in sun-dried fish (19.2–24.6 mg N/100 g), reflecting the shorter period during which autolytic and bacterial activity could proceed. After 30 days, TVB-N reached 38.4 mg N/100 g in S5-SD, exceeding the 35 mg N/100 g upper limit used in European regulation for some fish categories [16], while S10-SD (31.2) and S15-SD (27.6) were below it. All cabinet-dried samples remained at or below 28.6 mg N/100 g. Higher salt reduced day-30 TVB-N by about 27–28% when comparing 15% with 5% brine, and cabinet drying reduced it by about 25–26% at each salt level.

Table 4. TVB-N (mg N/100 g) and total plate count (log CFU/g) of dried bilih at day 0 and day 30 (mean ± SD, n = 3).

Parameter	S5-SD	S5-CD	S10-SD	S10-CD	S15-SD	S15-CD
TVB-N, day 0	24.6 ± 0.9	19.8 ± 0.8	21.4 ± 0.8	17.2 ± 0.7	19.2 ± 0.7	15.6 ± 0.6
TVB-N, day 30	38.4 ± 1.4	28.6 ± 1.1	31.2 ± 1.2	23.4 ± 0.9	27.6 ± 1.0	20.8 ± 0.8
Plate count, day 0	4.8 ± 0.2	3.9 ± 0.2	4.3 ± 0.2	3.5 ± 0.2	3.9 ± 0.2	3.1 ± 0.2
Plate count,	6.4 ± 0.2	5.1 ± 0.2	5.6 ± 0.2	4.4 ± 0.2	4.9 ± 0.2	3.8 ± 0.2

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day 30						

Fresh raw bilih: TVB-N 11.8 ± 0.5 mg N/100 g; plate count 4.6 ± 0.2 log CFU/g.

Microbial counts followed the same pattern. Sun-dried, lightly salted fish (S5-SD) increased by 1.6 log cycles during storage to 6.4 log CFU/g, while S15-CD increased by only 0.7 log to 3.8 log CFU/g. Pearson correlations across the 18 experimental units confirmed that salt content was negatively associated with day-30 TVB-N ($r = -0.86$, $p < 0.001$) and positively associated with day-30 TBARS ($r = 0.88$, $p < 0.001$), while aw was positively correlated with day-30 plate count ($r = 0.93$, $p < 0.001$). These relationships match the general understanding that lowering aw suppresses bacterial spoilage [9, 12], and they underline that the two quality dimensions, microbial and oxidative, respond to salt in opposite directions.

4.6. Sensory Acceptability

Sensory scores are presented in Table 5. S10-CD received the highest overall acceptability (4.3), with the best ratings for appearance, aroma, and texture. Cabinet-dried samples were generally preferred over sun-dried ones within each salt level, which panelists attributed to a lighter, more uniform color, absence of a stale or fishy odor, and a crisper texture after frying. Saltiness was well accepted at 5% and 10% brine, but the 15% brine products were judged too salty (scores 2.8–2.9), which dragged down their overall scores despite their better microbial stability. The sun-dried products were penalized for darker color and a slightly rancid note, which is consistent with their higher TBARS values.

Table 5. Sensory scores of fried dried bilih on a five-point hedonic scale (mean, n = 30 panelists).

Attribute	S5-SD	S5-CD	S10-SD	S10-CD	S15-SD	S15-CD
Appearance	3.5	4.0	3.8	4.3	3.6	3.9
Aroma	3.3	3.9	3.6	4.2	3.4	3.8
Saltiness	4.1	4.1	3.9	4.0	2.9	2.8
Texture (crispness)	3.3	3.9	3.7	4.4	3.5	4.0
Overall acceptability	3.4	3.9	3.7	4.3	3.3	3.6

Hedonic scale: 1 = dislike extremely; 5 = like extremely.

4.7. Integrated Assessment and Practical Recommendation

Because no single treatment was best on every criterion, treatments were ranked on aw, day-30 TBARS, day-30 TVB-N, and overall sensory score, and the ranks were summed (Table 6). S10-CD obtained the lowest rank sum (7.0) and was therefore the best overall compromise. It combined an aw below 0.70, day-30 TBARS below the indicative 2 mg MDA/kg reference, a day-30 TVB-N of 23.4 mg N/100 g, and the highest sensory score. S15-CD ranked second (9.0) because of its excellent microbial stability but was penalized for saltiness and higher oxidation, and S5-CD ranked third (10.5). All three sun-dried treatments ranked below all three cabinet-dried treatments.

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Table 6. Multi-criteria ranking of treatments (rank 1 = best; ties receive average ranks).

Treatment	aw	TBARS day 30	TVB-N day 30	Overall sensory	Rank sum	Final rank
S10-CD	2	2	2	1	7.0	1
S15-CD	1	3	1	4	9.0	2
S5-CD	3.5	1	4	2	10.5	3
S10-SD	5	5	5	3	18.0	4
S15-SD	3.5	6	3	6	18.5	5
S5-SD	6	4	6	5	21.0	6

Ranks assigned on aw (lower is better), TBARS and TVB-N at day 30 (lower is better), and overall sensory score (higher is better); equal weighting.

For processors around Lake Singkarak, these results suggest a simple and affordable upgrade: brine the fish at about 10% NaCl for 30 minutes and dry in a covered cabinet or solar-assisted dryer at around 55°C rather than in open air. If a cabinet dryer is not available, a lower brine concentration should not be chosen for sun drying, since S5-SD was the least stable product; covered solar tunnel dryers that approximate cabinet conditions would be a sensible intermediate option. Packaging in low-oxygen-permeability film, or with an oxygen absorber, would be expected to slow oxidation further and merits testing. The present study has limitations that should be acknowledged: storage was limited to 30 days at one temperature, only a single lot of fish from one site and season was used, and the sensory panel evaluated fried samples at day 0 only. Seasonal variation in fish fat content, which affects oxidation, and measurement of peroxide value and free fatty acids would give a fuller picture.

Conclusion

Brine concentration and drying method both significantly shaped the quality of dried bilih from Lake Singkarak, and they acted in partly opposing directions. Higher brine concentration lowered aw, TVB-N, and microbial counts but increased lipid oxidation and reduced consumer acceptance through excessive saltiness. Cabinet drying at 55°C produced lower moisture and aw, reduced TBARS by 37–39%, and slowed TVB-N and microbial growth during 30 days of ambient storage relative to sun drying at every salt level. Protein and calcium were retained, with the lower values at high salt explained mainly by dilution.

Salting in 10% brine followed by cabinet drying at 55°C (S10-CD) gave the best overall balance of stability, nutritional value, and sensory quality, and is recommended as a practical improvement over traditional practice. Future work should extend storage trials to several months and to different temperatures, include peroxide value, free fatty acids, and histamine and heavy metal screening, test low-oxygen packaging, evaluate calcium bioaccessibility using in vitro digestion, and assess seasonal and site variation in bilih composition.

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