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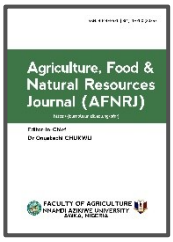

Original Article

Effects of sun-drying on the lipid quality and fatty acid composition of blue whiting (*Micromesistius poutassou*)

OPEN ACCESS

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ABSTRACT

The effects of sun-drying on the chemical composition, lipid quality, and fatty acid profile of blue whiting (Micromesistius poutassou) were investigated. Fifty fresh fish (300–400 g per fish) were eviscerated and randomly assigned to two groups: raw (control) and sun-dried. Fish designated for drying were exposed to sunlight for two consecutive days (08:00–17:00 h) until a final moisture content of 12.19 ± 0.81% was attained. Data were analysed using an independent-samples t-test, with statistical significance set at $p < 0.05$. Sun-drying significantly reduced the moisture content of blue whiting while increasing the relative concentrations of crude protein, crude fat, and ash. Oil extracted from sun-dried fish exhibited significantly higher peroxide value (9.76 vs. 4.95 meq O_2/kg), acid value (17.76 vs. 11.22 mg KOH/g), and free fatty acid content (9.03 vs. 5.64% oleic acid), but a lower iodine value (8.88 vs. 10.79 g I_2/100 g) than oil from raw fish, consistent with increased lipid oxidation and hydrolysis during drying. Sun-drying also significantly altered the fatty acid composition, increasing the relative proportion of saturated fatty acids while reducing the proportions of monounsaturated and polyunsaturated fatty acids. Overall, sun-drying effectively reduced the moisture content of blue whiting but was associated with deterioration in lipid quality and changes in the relative fatty acid composition. These changes may have implications for the nutritional quality and stability of dried blue whiting.

KEYWORDS: *Acid value, Iodine value, Moisture, Peroxide value, Saturated fatty acids*

INTRODUCTION

Fish is an important component of the human diet owing to its high nutritional value and health-promoting properties. It provides high-quality protein, essential amino acids, vitamins, minerals, and long-chain omega-3 polyunsaturated fatty acids (PUFAs), particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are associated with reduced risks of cardiovascular diseases and improved cognitive health (Ahmed *et al*., 2022; Chen *et al*., 2022). Consequently, fish plays a significant role in food and nutritional security, particularly in developing countries where it serves as an affordable source of animal protein (Bakhsh *et al*., 2023; Basurto *et al*., 2025).

Blue whiting (*Micromesistius poutassou*), popularly known as *Panla* in Nigeria, is one of the most widely consumed imported fish species because of its affordability, desirable sensory attributes, and relatively long storage life after drying (Agbabiaka *et al*., 2025; Omidiran *et al*., 2024; Sanda *et al*., 2026). However, its high moisture content and abundance of highly unsaturated lipids make fresh fish highly susceptible to post-harvest deterioration through microbial activity, enzymatic degradation, and oxidative reactions (Fawole &

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Oyelese, 2019). Effective preservation is therefore essential to minimize quality losses and extend shelf life (Aladejana *et al*., 2023; Odiko & Joseph, 2017).

Drying is one of the oldest and most widely used methods of fish preservation (Doe & Olley, 2020; Zhu *et al*., 2022). By lowering water activity, drying impedes microbial growth and slows enzymatic spoilage, thereby improving storage stability (Adeyeye, 2019; Doe & Olley, 2020). Among the available drying methods, open-air sun-drying remains the most economical and accessible technique in many tropical countries because it requires minimal capital investment and energy input (Fitri *et al*., 2022; Mazur *et al*., 2013). Nevertheless, exposure to fluctuating temperatures, oxygen, sunlight, dust, insects, and other environmental contaminants during sun- drying may compromise product quality and accelerate chemical deterioration (Adeyeye, 2019; Fitri *et al*., 2022).

Fish lipids are particularly susceptible to deterioration because of their relatively high content of unsaturated fatty acids, including EPA and DHA (Secci & Parisi, 2016; Suárez-Medina *et al*., 2024). During drying, exposure to oxygen, heat, and solar radiation can promote lipid oxidation, leading to the formation of hydroperoxides and subsequent secondary oxidation products, some of which contribute to rancid odours and undesirable flavours (Chaijan *et al*., 2017; Chen *et al*., 2023; Cui *et al*., 2023; Tenyang *et al*., 2020). In contrast, lipid hydrolysis involves the cleavage of ester bonds in triacylglycerols, resulting in the release of free fatty acids and other hydrolytic products (Menalla *et al*., 2024). Hydrolysis may be promoted by endogenous or microbial lipases and is commonly assessed using acid value or free fatty acid content. Although oxidation and hydrolysis are distinct processes, they may occur concurrently during fish processing and can collectively affect lipid quality and nutritional value.

Several studies have investigated the effects of frying, smoking, oven-drying, and other thermal processing techniques on the nutritional profile and lipid stability of various fish species (Chaijan *et al*., 2017; Chen *et al*., 2023; Cui *et al*., 2023; Tenyang *et al*., 2020). However, information on the effects of traditional sun-drying on the lipid quality of blue whiting remains limited, particularly regarding changes in lipid oxidation, lipid hydrolysis, and fatty acid composition under ambient drying conditions, despite the consumption of dried fish in Nigeria. Therefore, evaluating changes in lipid oxidation and hydrolysis during the drying of blue whiting is important for understanding their effects on lipid quality and nutritional value (Fitri *et al*., 2022).

Accordingly, this study evaluated the influence of traditional sun-drying on the lipid quality of blue whiting by determining changes in its proximate composition, lipid oxidation, lipid hydrolysis and fatty acid composition. The findings provide species-specific information on the chemical and lipid changes associated with traditional sun-drying under ambient conditions and may contribute to improved processing and handling practices for maintaining the nutritional and overall quality of dried blue whiting.

MATERIALS AND METHOD

Collection and preparation of fish samples

Fresh blue whiting was purchased from the same batch at a retail fish market in Ilorin, Kwara State, Nigeria. A total of 50 whole fish, weighing 300–400 g each and measuring 20–30 cm in length, were used for the study. Immediately after purchase, the fish were transported to the laboratory in insulated iceboxes. Upon arrival, the fish were eviscerated, beheaded, and thoroughly rinsed with potable water to remove residual blood and other adhering materials. The fish were then randomly divided into two groups of 25 fish each.

The first group served as the fresh (raw) control. The 25 fish were randomly divided into three groups containing 8, 8, and 9 fish, respectively. Each group was filleted and homogenized separately to constitute one independent biological replicate, resulting in three independent replicates for the fresh fish treatment. The homogenized samples were individually packaged in airtight polyethylene bags and stored at −18°C until further analysis. The second group of 25 fish was subjected to sun-drying as described below.

Sun-drying of fish

The cleaned fish in the second group (25 fish) were split longitudinally into two approximately equal halves by making a continuous cut along the length of the fish body from the head region toward the tail, while leaving the two halves attached at the caudal region. The split fish were arranged in a single layer on aluminum trays covered with clean mosquito netting to protect them from insects, dust, and other environmental contaminants. The trays were placed outdoors and exposed to direct sunlight from 08:00 to 17:00 h for two consecutive days during the dry season under ambient environmental conditions. During the drying period, the ambient temperature ranged from 25 to 40°C, the average relative humidity was approximately 26%, and the mean wind speed was 13.3 km h^{-1}. The fish were turned at regular intervals to promote uniform exposure and drying. Drying was continued until the samples reached the predetermined target moisture content. After drying, the 25 fish were randomly divided into three portions containing 8, 8, and 9 fish, respectively. Each portion was homogenized separately to constitute one independent biological replicate, resulting in three independent replicates for the sun-dried fish treatment. The homogenized samples were individually packaged in airtight polyethylene bags and stored in a freezer at −18°C until further analysis.

Chemical composition

Chemical (moisture, crude protein, crude fat, and ash) composition of the fresh and sun-dried blue whiting samples was determined according to the Official Methods of Analysis of AOAC (2019). All determinations were carried out in

triplicate for each treatment. Moisture content was determined by the air-oven drying at 105°C to constant weight (AOAC Method 950.46). Crude protein was determined by the Kjeldahl method using a nitrogen conversion factor of 6.25 (AOAC Method 940.25). Crude fat was determined by the Soxhlet solvent extraction method (AOAC Method 945.16). Ash content was determined by incineration in a muffle furnace at 550°C (AOAC Method 938.08).

Extraction of fish oil

Oil was extracted from the fresh and sun-dried blue whiting samples using a Soxhlet solvent extraction apparatus. Approximately 100 g of each homogenized fish sample was accurately weighed into a cellulose extraction thimble and placed in the Soxhlet extractor. n-Hexane was used as the extraction solvent. Prior to extraction, the extraction flask was dried, cooled in a desiccator, and weighed. The Soxhlet apparatus was assembled, and the samples were continuously extracted with n-hexane under reflux for approximately 3 h. During extraction, the solvent repeatedly evaporated, condensed, and passed through the sample, dissolving the lipid fraction before returning to the extraction flask through the siphoning process. At the end of the extraction period, the n-hexane was recovered and removed from the extraction flask under reduced pressure using a rotary evaporator. The extracted oil was further dried to remove residual solvent, cooled in a desiccator, and weighed to determine the oil yield. The extracted oil was transferred into clean, dry, airtight amber glass vials and stored at 4°C until subsequent analyses.

Peroxide value

Peroxide value (PV) was determined as per the iodometric titration procedure of AOCS Official Method Cd 8b-90. Briefly, 5.0 g of extracted oil was dissolved in a glacial acetic acid mixture (3:2, v/v). Approximately 0.5 mL saturated potassium iodide was added, and the mixture was allowed to stand in the dark for 10 min. Distilled water (30 mL) and 0.5 mL of 1% starch solution were then added before titration with 0.01 mol/L sodium thiosulphate until the yellow color has almost disappeared. A reagent blank was determined simultaneously. The peroxide value was calculated from the blank-corrected volume of sodium thiosulfate and expressed as milliequivalents of active oxygen per kilogram of oil (meq O_2/kg oil).

The peroxide value was calculated as:

$$PV = \frac{Vs - Vb \times N \times 1000}{W} \quad (1)$$

Where PV = peroxide value (meq O_2/kg oil); V_s = volume of sodium thiosulfate used for sample (mL); V_b = volume used for blank (mL); N = normality of sodium thiosulfate and W = mass of oil sample (g).

Iodine value

The iodine value (IV) of the fish oil samples was determined following Wijs method (AOCS Method Cd 1d-92). Briefly, approximately 0.3 g of extracted oil was dissolved in 10 mL of cyclohexane in a glass-stoppered flask. Subsequently, 25 mL of Wijs reagent (iodine monochloride solution in glacial acetic acid) was added, and the flask was immediately stoppered, mixed thoroughly and kept in the dark at room temperature for 30 min. Thereafter, 20 mL of potassium iodide solution (approximately 10%) and 100 mL of distilled water were added. The liberated iodine was titrated with standardized 0.1 N sodium thiosulfate solution until the yellow colour became pale. Fresh starch indicator was then added, and titration was continued until the blue colour disappeared. A reagent blank was determined simultaneously under identical conditions without the oil sample. The iodine value was calculated from the difference between the blank and sample titres and expressed as grams of iodine absorbed per 100 g of oil (g I_2/100 g). Results were expressed as grams of iodine absorbed per 100 g of oil.

The iodine value is calculated as:

$$IV = \frac{(B-S)\times N\times 12.69}{W} \quad (2)$$

Where: IV = iodine value (g I_2/100 g oil), B = volume (mL) of sodium thiosulfate used for the blank, S = volume (mL) of sodium thiosulfate used for the sample, N = normality of sodium thiosulfate, W = weight of oil sample (g) and 12.69 = conversion factor for 0.1 N sodium thiosulfate.

Acid value

Acid value was determined according to AOCS Official Method Cd 3d-63. Briefly, 0.5 g of extracted oil was dissolved in an ethanol ether mixture (1:1, v/v), followed by the addition of phenolphthalein indicator. The mixture was titrated against 0.1 M potassium hydroxide with continuous shaking until a persistent pale-pink endpoint was obtained. The acid value (AV) was calculated from the volume of KOH required to neutralize the free fatty acids in the oil and it was expressed as mg KOH/g oil.

$$AV = \frac{V\ X\ C\ X\ 56.1}{W} \quad (3)$$

Where AV = acid value (mg KOH/g oil), V = volume of KOH used for titration (mL), corrected for the blank if applicable, C = concentration of KOH (mol/L), 56.1 = molecular weight of KOH (g/mol) and W = weight of oil sample (g).

Free fatty acid (FFA)

The free fatty acid (FFA) content was calculated from the acid value and expressed as percentage oleic acid, using the relationship:

$$FFA\ (\%\ as\ oleic\ acid) = AV \times 0.503 \quad (3)$$

where AV is the acid value expressed as mg KOH/g oil.

Fatty acid analysis

Approximately 1 g of the extracted lipid was transferred into a reaction tube for the preparation of fatty acid methyl esters (FAMEs). The lipid was saponified with 0.66 N methanolic potassium hydroxide (KOH), followed by methylation with 14% boron trifluoride (BF_3) in methanol to convert the fatty acids to their corresponding methyl esters. Methyl heneicosanoate was used as the internal standard. Following methylation, the FAMEs were recovered, transferred into amber GC vials, and stored at −18°C until gas chromatographic analysis.

The FAMEs were separated and analysed using a Shimadzu GC-2014 gas chromatograph (Shimadzu Corporation, Tokyo, Japan) equipped with a flame ionization detector (FID) and an HP-88 fused-silica capillary column (100 m × 0.25 mm internal diameter × 0.20 µm film thickness; Agilent Technologies, Santa Clara, CA, USA). The chromatographic conditions were as follows: injection volume, 1 µL; split ratio, 1:50; initial oven temperature, 130°C, held for 1 min; increased to 170°C at 6.5°C/min; subsequently increased to 215°C at 2.75°C/min and held for 12 min; and finally increased to 230°C at 4 °C/min and held for 3 min. The FID temperature was maintained at 280°C.

Individual fatty acids were identified by comparing their retention times with those of a 37-component FAME reference standard (Supelco, Bellefonte, PA, USA) analysed under the same chromatographic conditions. The fatty acid concentrations were calculated using methyl heneicosanoate as the internal standard. The concentration of each identified fatty acid was calculated from the ratio of its peak area to that of the internal standard, taking into account the amount of internal standard used and the corresponding detector response. The resulting individual fatty acid concentrations were normalized to the sum of all identified fatty acids and expressed as percentage of total identified fatty acids. All analyses were performed in triplicate.

Statistical analysis

All analytical determinations were performed using three independent replicates per treatment ($n = 3$), with each replicate consisting of a homogenized pool of fish samples prepared as described in the sample preparation procedure. Thus, the experimental unit for statistical analysis was the pooled sample rather than the individual fish, and the data were not treated as independent observations at the individual fish level. Results were expressed as mean ± standard deviation (SD). Data were analysed using two tailed independent samples *t* tests in IBM SPSS Statistics version 20 (IBM Corp., Armonk, NY, USA), because the raw and sun-dried fish samples represented independent experimental units and were not paired. Prior to analysis, the assumptions of the *t* test, including approximate normality and homogeneity of variance, were assessed. Equal variances were assumed when the homogeneity of variance assumption was satisfied; otherwise, the unequal variance version of the *t* test was used. For the fatty acid profile, multiple comparisons were accounted for by adjusting the resulting *P* values using the Benjamini Hochberg false discovery rate procedure. Statistical significance was declared at an adjusted $P < 0.05$ for the fatty acid profile and at $P < 0.05$ for the other variables.

RESULTS AND DISCUSSION

Chemical composition of blue whiting

The chemical composition of raw and sun-dried blue whiting is presented in Table 1. Compared with the raw fish, the sun-dried samples had significantly lower moisture content but significantly higher crude protein, crude fat, and ash contents. These changes are primarily attributable to moisture loss during drying, which concentrates the remaining nutrients on a wet-weight basis.

The marked reduction in moisture content demonstrates the effectiveness of sun-drying in removing water from blue whiting. Reduction in moisture content can contribute to improved storage stability by limiting the availability of water for microbial growth and other moisture-dependent deteriorative reactions. The moisture content of the sun-dried fish (12.19 ± 0.81%) was below the 15% level reported as a desirable moisture content for dried fish products (Immaculate *et al*., 2012), suggesting that the product would possess improved storage stability if handled and stored under appropriate conditions. Similar reductions in moisture content following sun-drying have been reported in recent studies on different fish species (Zhu *et al*., 2022; Al-Saadi *et al*., 2023; Birie *et al*., 2025). Moisture content is an important quality parameter in dried fish because excessive residual moisture can favour microbial growth and accelerate physicochemical deterioration during storage. Therefore, adequate moisture removal is an important consideration in the processing and subsequent storage of dried fish products.

The significant increases in crude protein, crude fat, and ash contents observed after sun-drying were largely attributable to the concentration effect resulting from moisture removal rather than a net increase in these nutrients. As water is removed during drying, the remaining constituents become concentrated, resulting in higher concentrations when expressed on a wet-weight basis. Comparable concentration-related increases in protein, lipid, and ash contents have been reported following fish drying (Adeyeye *et al*., 2015; Tenyang *et al*., 2020). The increase in crude protein concentration indicates that protein became more concentrated following dehydration; however, it does not by itself establish that no protein degradation or nitrogen loss occurred during drying. On the whole, sun-drying substantially reduced the moisture content of blue whiting and increased the measured concentrations of crude protein, crude fat, and ash. These changes are consistent with the concentration effect associated

with dehydration and describe the proximate compositional changes observed under the conditions used in this study.

Table 1: Effect of sun-drying on chemical composition of blue whiting fish

Chemical composition (%)	Fresh	Sun-dried	*P* value
Moisture	64.43 ± 3.01	12.19 ± 0.81	<0.0001
Crude Protein	18.25 ± 0.22	35.99 ± 0.71	<.00001
Crude fat	6.06 ± 0.01	11.21 ± 0.01	<0.0001
Ash	4.84 ± 0.01	8.02 ± 0.01	<0.0001

Values are mean ± standard deviation.

Lipid oxidation of blue whiting

Lipid oxidation is one of the major causes of quality deterioration in fish during processing and storage because fish lipids are rich in highly unsaturated fatty acids that are particularly susceptible to oxidative degradation. Oxidative reactions can reduce the nutritional quality and storage stability of fish products and promote the formation of rancid odours and off-flavours, thereby adversely affecting consumer acceptability (Chaijan *et al*., 2017; Cui *et al*., 2023; Tenyang *et al*., 2020). The lipid quality indices of oils extracted from raw and sun-dried blue whiting are presented in Table 2. Compared with the raw fish, the oil extracted from the sun-dried samples had significantly higher peroxide value, acid value, and free fatty acid (FFA) content, but a significantly lower iodine value.

Free fatty acids are primarily formed through the hydrolysis of triacylglycerols and phospholipids by endogenous lipolytic enzymes and, under certain conditions, microbial lipases (Xu *et al*., 2018). The significant increase in FFA content following sun-drying suggests that hydrolytic degradation of fish lipids occurred during processing. This increase may be associated with prolonged exposure of the fish to ambient conditions during drying, which may have favoured the activity of endogenous lipolytic enzymes. Accumulation of FFAs is undesirable because free fatty acids can undergo further oxidative reactions and may contribute to the development of undesirable flavours and odours in fish products (Cheng *et al*., 2024; Wang & Zheng, 2025).

The iodine value, which provides an indication of the degree of unsaturation of lipids, decreased significantly following sun-drying. This reduction suggests a decrease in the number of carbon-carbon double bonds, potentially as a result of oxidation of unsaturated fatty acids during processing. Exposure to atmospheric oxygen, solar radiation, and elevated ambient temperatures during sun-drying may accelerate oxidative reactions, resulting in the consumption of unsaturated bonds and a consequent reduction in iodine value (Womeni *et al*., 2016). The decrease in iodine value observed in the present study was accompanied by an increase in peroxide value, providing further evidence of oxidative changes in the lipids during sun-drying.

Peroxide value is widely used as an indicator of primary lipid oxidation because it reflects the formation of lipid hydroperoxides during the early stages of oxidative deterioration (Zhang *et al*., 2021). The significantly higher peroxide value observed in the sun-dried samples indicates that primary lipid oxidation increased during the drying process. However, the peroxide values remained below the reported maximum limit of 10 meq O_2/kg oil for acceptable edible oil quality, suggesting that extensive primary oxidation had not occurred at the point of analysis (Codex Alimentarius Commission, 2017; Ismail *et al*., 2016). Similar increases in peroxide value during fish drying have been reported for different fish species (Shah *et al*., 2009; Tenyang *et al*., 2020). Such increases have been attributed to exposure to oxygen, solar radiation, and elevated temperatures during drying, which can promote the formation of lipid hydroperoxides.

Overall, the concurrent increase in peroxide value, acid value, and FFA content, together with the reduction in iodine value, indicates that sun-drying promoted both oxidative and hydrolytic changes in blue whiting lipids. The increase in peroxide value suggests enhanced formation of primary oxidation products, whereas the increases in acid value and FFA content indicate increased hydrolytic degradation. The observed reduction in iodine value further suggests a decrease in lipid unsaturation, which may be associated with oxidation of unsaturated fatty acids. Collectively, these changes indicate a deterioration in lipid quality following sun-drying and may have implications for the sensory quality, oxidative stability, and nutritional value of the dried fish.

Table 2: Changes in the lipid quality of blue whiting oil following sun-drying

Lipid oxidation parameters	Fresh	Sun dried	*P* value
Iodine value (g I_2/100 g of oil)	10.79 ± 0.73	8.88 ± 0.31	0.002
Acid value ((mg KOH/g of lipid)	11.22 ± 1.01	17.96± 1.03	<0.0001
Free fatty acid (% oleic acid)	5.64 ± 0.51	9.03 ± 0.52	<0.0001
Peroxide value (meq O_2/kg of lipid))	4.95 ± 0.41	9.76 ± 0.78	<0.0001

Values are mean ± standard deviation.

Fatty acid composition of blue whiting

The fatty acid composition of oils extracted from raw and sun-dried blue whiting is presented in Table 3. The fatty acids detected in the present study were consistent with those previously reported for blue whiting (Kolade, 2015). Sun-drying significantly altered the fatty acid profile of the fish oil. Compared with the raw fish, the oil extracted from the sun-dried samples contained significantly higher proportions of lauric, myristic, palmitic, stearic, arachidic, and behenic acids. In contrast, the proportions of palmitoleic, oleic, linoleic, α-linolenic, arachidonic, eicosapentaenoic (EPA), docosapentaenoic (DPA), and docosahexaenoic (DHA) acids were significantly lower following sun-drying. Consequently, the proportion of total saturated fatty acids (SFA) increased, whereas the proportions of total monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) decreased in the sun-dried fish.

The apparent increase in the proportion of saturated fatty acids is likely a relative effect associated with the preferential degradation of unsaturated fatty acids during sun-drying rather than a true increase in their absolute content. Unsaturated fatty acids, particularly PUFA, contain multiple double bonds that make them susceptible to oxidative degradation in the presence of oxygen, light, and elevated temperatures. Thus, the degradation of MUFA and PUFA during processing can result in an increased relative contribution of the more oxidation-resistant saturated fatty acids to the total fatty acid profile (Secci & Parisi, 2016). The marked reductions in EPA and DHA are of particular nutritional importance because these long-chain omega-3 fatty acids are associated with cardiovascular, neurological, and anti-inflammatory functions (Elgar, 2022).

Table 3: Changes in the fatty acid profile of blue whiting following sun-drying

Fatty acid (% of total FA)	Raw	Dried	*p*-value	BH-adjusted *p*-value
C12:0, lauric acid	1.21 ± 0.01	2.69 ± 0.03	<0.0001	<0.0001
C14:0, myristic acid	6.32 ± 0.72	9.71 ± 0.60	<0.0001	<0.0001
C16:0, palmitic acid	11.92 ± 1.00	19.62 ± 1.91	<0.0001	<0.0001
C17:0, margaric acid	1.44 ± 0.09	1.42 ± 0.09	0.604	0.604
C18:0, stearic acid	2.45 ± 0.22	6.98 ± 0.90	<0.0001	<0.0001
C20:0, arachidic acid	0.65 ± 0.12	1.74 ± 0.07	<0.0001	<0.0001
C22:0, behenic acid	0.33 ± 0.03	1.54 ± 0.12	0.0011	0.0012
C16:1n-7, palmitoleic acid	3.22 ± 0.56	3.04 ± 0.45	<0.0001	<0.0002
C16:1n-9, cis-7-hexadecenoic acid	0.78 ± 0.10	0.32 ± 0.05	<0.0001	<0.0001
C18:1n-9, oleic acid	10.45 ± 1.01	8.56 ± 1.00	<0.0001	<0.0001
C20:1n-9, eicosenoic acid	14.56 ± 1.43	12.21 ± 1.45	<0.0001	<0.0001
C18:2n-6, linoleic acid	7.30 ± 0.92	5.11 ± 0.27	<0.0001	<0.0001
C18:3n-3, alpha-linolenic acid	7.10 ± 0.61	4.22 ± 0.33	0.0004	0.0006
C18:3n-6, gamma-linolenic acid	0.67 ± 0.46	0.35 ± 0.01	0.0013	0.0016
C20:4n-3, eicosatetraenoic acid	2.10 ± 0.05	1.71 ± 0.05	0.0024	0.0026
C20:3n-6, dihomo-gamma-linolenic acid	0.37 ± 0.02	0.23 ± 0.01	0.0009	0.0001
C20:4n-6, arachidonic acid	4.00 ± 0.12	2.00 ± 0.09	0.0001	0.0002
C20:5n-3, eicosapentaenoic acid	8.34 ± 0.98	6.22 ± 0.71	<0.0001	<0.0001
C22:5n-3, docosapentaenoic acid	4.10 ± 0.16	2.45 ± 0.13	<0.0001	<0.0001
C22:6n-3, docosahexaenoic acid	12.67 ± 1.03	9.22 ± 1.12	<0.0001	<0.0001
ΣSFA	24.32 ± 2.10	43.70 ± 4.38	<0.0001	<0.0001
ΣMUFA	29.01 ± 2.04	24.13 ± 2.22	<0.0001	<0.0001
ΣPUFA	46.67 ± 4.12	31.51 ± 3.01	<0.0001	<0.0001
ΣUFA	75.68 ± 6.02	55.64 ± 4.41	<0.0001	<0.0001
Σn-6	11.88 ± 1.46	7.69 ± 0.88	<0.0001	<0.0001
Σn-3	25.11 ± 2.04	17.89 ± 1.27	<0.0001	<0.0001
Σn-6/Σn-3	0.47 ± 0.01	0.43 ± 0.01	0.0005	0.0006
ΣPUFA/ΣSFA	1.91 ± 0.17	0.72 ± 0.12	<0.0001	<0.0001

Values are mean ± standard deviation. Where; ΣSFA= total saturated FA content, ΣMUFA= total monounsaturated FA content, ΣPUFA= total polyunsaturated FA content, ΣUFA= total unsaturated FA content, Σn-6= total n-6 PUFA, Σn-3= total n-3 PUFA, BH= Benjamini–Hochberg.

The PUFA/SFA ratio is commonly used as an index of the nutritional quality of dietary lipids, with values above 0.4 generally considered desirable (Monnard & Dulloo, 2021). In the present study, both raw and sun-dried blue whiting oils had PUFA/SFA ratios above this reference value; however, the significantly lower ratio observed after sun-drying indicates a relative reduction in the nutritional quality of the lipid fraction. This reduction was mainly associated with the greater decline

in PUFA relative to SFA during processing and is consistent with the susceptibility of PUFA to oxidative degradation.

The n-6/n-3 PUFA ratio is another nutritional index commonly used to evaluate the balance between omega-6 and omega-3 fatty acids. Dietary recommendations have suggested maintaining this ratio below 4:1 (Gebauer *et al*., 2019). In the present study, sun-drying did not significantly affect the n-6/n-3 PUFA ratio, indicating that the reductions in omega-6 and omega-3 fatty acids occurred without a substantial alteration in their relative proportions. Thus, despite the observed changes in individual fatty acids, the overall balance between n-6 and n-3 PUFA remained relatively stable following sun-drying.

Overall, the changes in fatty acid composition provide additional evidence of lipid deterioration during sun-drying. The reductions in nutritionally important unsaturated fatty acids, particularly EPA and DHA, together with the increase in the relative proportion of SFA and the decline in the PUFA/SFA ratio, suggest that sun-drying adversely affected the nutritional quality of the lipid fraction. These changes are consistent with the increases in peroxide value, acid value, and free fatty acid content observed in the present study, supporting the occurrence of oxidative and hydrolytic deterioration of blue whiting lipids during sun-drying.

CONCLUSION AND RECOMMENDATION

Sun-drying significantly altered the chemical composition and lipid quality of blue whiting fish. The process substantially reduced moisture content, which may contribute to improved storage stability, while increasing the relative concentrations of protein, fat, and ash as a consequence of moisture loss. Sun-drying also promoted both lipid hydrolysis and oxidation, as indicated by increases in acid value, free fatty acid content, and peroxide value, together with a reduction in iodine value. These changes were accompanied by reductions in nutritionally important unsaturated fatty acids, particularly eicosapentaenoic acid and docosahexaenoic acid, and a decrease in the PUFA/SFA ratio. Overall, the findings indicate that although sun-drying effectively reduces moisture, it can adversely affect the lipid quality and nutritional value of blue whiting through hydrolytic and oxidative deterioration. Therefore, optimization of drying conditions or adoption of alternative drying technologies may help minimize lipid deterioration and better preserve the nutritional quality of dried blue whiting.

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Authors' Contributions

RMS conceptualised the study, carried out the experiments, collected, analysed and interpreted the data, and wrote the first draft of the manuscript. OOF supervised the research and critically reviewed the manuscript, and provided overall academic guidance. All authors have read and agreed to the final version of the manuscript.

Ethical Statement

Not applicable

AI Declaration Statement

The authors declare that Grammarly was used for improving the use of English in the manuscript. All outputs were critically reviewed, verified, and approved by the authors, who accept full responsibility for the content of the manuscript.

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