



# Compositional Analysis of “Masmin” -a Traditional Smoke-Dried Fishery Product from Lakshadweep Islands, India.

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## Abstract

The Lakshadweep Islands are situated in the mid-sea, about 400 km away from mainland India, and form a vital source for the blue revolution in the country, having significant potential to boost the marine seafood sector. Smoke-dried tuna, locally known as *masmin*, is a staple seafood that meets one of the major protein demands of the islanders. Traditionally, *masmin* is prepared by smoke-drying cooked skipjack tuna (*Katsuwonus pelamis*), and the processing has been practiced since time immemorial in the islands. Understanding the compositional characteristics of traditional *masmin* is essential for assessing its nutritional value and for optimising its processing for broader applications within the Indian seafood industry. The present study evaluated the moisture, crude protein, fat, ash, sodium chloride (%NaCl), pH, and total phenolic content (TPC) of *masmin* samples collected from five different islands. The average moisture content varied significantly, ranging from  $14.76 \pm 1.29\%$  in samples from Minicoy to  $20.65 \pm 1.56\%$  in those from Amini. Crude protein levels across the five island samples ranged between  $58.78 \pm 0.36$  and  $78.75 \pm 0.02$  g/100 g, indicating the high nutritional value of traditionally smoke-dried tuna. The highest total phenolic content ( $16.51 \pm 0.34$  mg GAE/g) was observed in the sample from Minicoy, while the

lowest ( $6.78 \pm 0.91$  mg GAE/g) was recorded in the sample from Kavaratti. The high phenolic content in Minicoy samples is likely due to extended drying and smoking durations, as well as mass loss from moisture reduction, which concentrates phenolic compounds. Overall, differences in traditional processing methods and ingredients used across the islands have led to notable variations in the final composition of *masmin*, highlighting the importance of standardisation for quality assurance and nutritional consistency.

**Keywords:** *Masmin*, nutritional composition, total phenolic content, Lakshadweep, smoke-dried tuna

## Introduction

The Lakshadweep Islands, located over 400 km off the southwest coast of India in the Arabian Sea, are well known for their diverse fishery resources, vibrant coral reefs, and crystal-clear turquoise waters. The livelihood opportunities of the islanders rely mainly upon the natural resources, such as the fisheries and coconut cultivation, which serve as the principal source of income. The tuna fisheries, non-tuna fisheries and the marine ornamental fishes constitute the fishery resources of the islands. Among all, tunas and tuna-like species contribute the most to the total landings in the islands. According to FAO (2024), the western Indian Ocean (area 51, sub-area 51.4) is one of the major contributors of tunas and tuna-like species. In 2023, marine fish landings in the Lakshadweep Islands totalled 14,430 tonnes, with tuna accounting for 11,620 tonnes (80.5%), of which skipjack tuna made up 70% (CMFRI, 2024). According to FAO (2024),

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skipjack tuna was the third-largest contributor to global marine capture production in 2022.

According to Vinay, Ramasubramanian, Krishnan, Kumar, and Ayoob (2017), 90% of the landed tuna in the Lakshadweep Islands is utilised for *masmin* production. In line with this, the present observation also suggested that approximately 10–12% of the total skipjack tuna caught is sold fresh, and the remaining 88–90% of the catch is utilised in the traditional *masmin* industry. *Masmin* is a traditionally cooked, smoked, and dried loin from skipjack tuna (*Katsuwonus pelamis*), and the traditional processing of tuna preservation has been practiced since time immemorial in the islands. The *masmin* industry has become one of the major sources of income, and the livelihood of fishermen depends on the production and sale of traditional *masmin* in the domestic and overseas markets in Sri Lanka, Singapore, and Malaysia.

Smoking is a critical step in the preparation of *masmin*, as it not only imparts a characteristic flavour and aroma to the product but also enhances its shelf life through the antimicrobial properties of phenolic compounds present in the smoke. Globally, several smoke-dried products similar to *masmin* are found across Asian countries. *Katsuobushi*, a well-known Japanese delicacy, is made from smoked, dried, and fermented skipjack tuna (Park, Yu, Ko, & Park, 2024). Similarly, *Keumamah* is a traditional Indonesian food, also typically prepared from skipjack tuna, and closely resembles *katsuobushi*. In the Maldives, *Hikimas* is a popular product made by hot-smoking, drying, and salting tuna (Naila, Flint, Fletcher, Bremer, & Meerdink, 2011). These examples highlight the international significance of *masmin*-like products in the global seafood trade. Despite its cultural and economic importance, traditional *masmin*, which supports the livelihood of nearly 65,000 islanders in the Lakshadweep islands, has received limited scientific attention and more research is needed to promote *masmin* as a globally recognized smoked fish product.

However, traditional *masmin* preparation varies significantly across the islands, leading to inconsistencies in its nutritional composition. These variations arise from differences in local processing practices and ingredients used across the ten inhabited islands, which are dispersed over a stretch of 204 nautical miles. In many cases, the exact production date is not known, further complicating

standardization. The localized methods of cooking, smoking, and drying contribute to the distinctive flavour and quality of *masmin* produced on each island. With this background, the present study aims to evaluate the existing chemical composition of *masmin* in relation to its processing variations across the Lakshadweep Islands.

## Materials and Methods

Thirty-four *masmin* samples, each weighing approximately 500 g, were collected from different islands of Lakshadweep, namely Agatti, Amini, Kalpeni, Kavaratti, and Minicoy (Table 1). The study areas were selected based on maximum production and the availability of raw material, as Agatti, Kavaratti, Amini, and Minicoy are the major fish landing centres (CMFRI, 2023) and also the principal *masmin*-producing islands. The collected samples were packed in an airtight polythene bag and brought to the laboratory for analysis. Further, all 34 samples were individually ground into a powder using a dry grinder and then stored in an airtight container for further analysis. The chemical composition parameters analysed for *masmin* include moisture, protein, lipid, ash, total phenolic content, pH, and % NaCl, for which samples were analysed in triplicate.

Table 1. Details of sample collection

Sl. No.	Name of the Island	Number of samples collected (N)
1.	Agatti	9
2.	Amini	3
3.	Kalpeni	3
4.	Kavaratti	5
5.	Minicoy	14

In the traditional method of *masmin* preparation, the fish is initially made into fillets (skin on), washed with clean seawater/fresh water, and cooked in seawater. The entire process of cooking is carried out for 2 to 3 hours and left until it cools to room temperature. The cooked tunas are then opened into two halves and subjected to the smoking process with locally available coconut husk and leaves as a fuel source. The smoking process is continued for 2 to 4 hours until the product turns golden brown in colour. The final stage of *masmin* processing is sun drying, which is carried out for 10 to 15 days (i.e.,

Table 2. Process variations in traditional *masmin* preparation across different Lakshadweep islands

Sl. No	Island	Respondent (N)	Duration of cooking (hours)	Duration of smoking (hours)	Duration of drying (days)
1	Minicoy	15	2-3*	4 (3-4 days)	10-15
2	Agatti	10	2-3	2-3	7-10
3	Kavaratti	10	3	2-3	7-12
4	Amini	3	3	2-3	7-10
5	Kalpeni	1	2-3	2-3	7-10

\*Boiled twice with one interval

8–12 hours of proper sunlight per day) until the product becomes brittle and hard, and the moisture content is reduced to below approximately 15%. Under proper packaging conditions, it can be stored for 1–2 years (Varghese, 1987; David, Rajagopalaswami, & Sugumar, 1990; Nithin et al., 2016; Patel & Halder, 2019). In the present study, the process variations of *masmin* were analysed by the survey among the fishermen of Agatti, Amini, Kalpeni, Kavaratti, and Minicoy. The survey was mainly focused on the duration of cooking, smoking and drying and the duration was calculated by averaging the responses from multiple respondents, and the results are given in Table 2.

The moisture content of *masmin* was estimated by the direct heating method (AOAC, 2000). About 10 g of sample was taken in a petri dish and dried in a hot air oven (Technico Laboratory Products Pvt. Ltd., Chennai, India) with mechanical convection at  $100 \pm 2$  °C for 16-18 hours. The final weight of the dried sample was taken and recorded. The weight loss was expressed as a percentage of the moisture content of the *masmin*. The crude protein of powdered *masmin* was measured using the Kjeldahl apparatus (Pelican, Kelpplus-Kelvac VA, Mumbai, India). The dry *masmin* sample was digested in "Pelican Kelpplus KES 12L VADLS" in the presence of a digestion mixture ( $\text{CuSO}_4$  and  $\text{K}_2\text{SO}_4$ ), and concentrated  $\text{H}_2\text{SO}_4$ . The distillation process was carried out by dissolving liberated ammonia in the receiver flask containing boric acid and Tashiro's indicator. The contents were titrated with acid until the colour changed from green to pink, and the crude protein content was determined by multiplying the percentage of nitrogen by 6.25 (AOAC, 2000). Crude fat content was determined following the AOAC (2000) method, in which fat was extracted with petroleum ether (boiling point: 60–80 °C) using a Soxhlet apparatus (EXPO HI-TECH, Soxhlet extraction heater mantle type, Mumbai, India) for

about 6–8 hours at a condensation rate of 5–6 drops per second. Ash content was estimated using a muffle furnace (EXPO Hi-TECH, i-therm AL-7941, Mumbai, India). Crucibles containing 1–2 g of carbonized samples were placed in the furnace and incinerated at  $600 \pm 5$  °C for about 6 hours until white ash was obtained. Weight difference before and after was recorded, and ash was expressed as a percentage (AOAC, 2000).

The salt content (%NaCl) was estimated using Mohr's method (Belcher, Macdonald, & Parry, 1957), in which 0.1 N silver nitrate was used for titration. The pH of the sample was measured using a digital pH meter (Eutech Tutor pH/°C meter, Eutech Instruments, Singapore), previously calibrated with buffer solutions of pH 4.0, 7.0, and 9.0. The total phenolic content (TPC) of the sample was determined using the Folin–Ciocalteu method, as modified from Singleton (1999). Two grams of the sample were homogenized in 80% methanol, centrifuged at 10,000 rpm for 15 minutes, and the residue was re-extracted with methanol. The supernatants were combined, evaporated, and redissolved in 5 mL of distilled water. A 0.1 mL aliquot was mixed with 2 mL of 2% sodium carbonate and, after 3 minutes, 0.1 mL of (50%) Folin–Ciocalteu reagent was added. The volume was adjusted to 5 mL with distilled water, incubated in the dark for 30 minutes, and the absorbance was measured at 725 nm using gallic acid as the standard. Results are expressed as mg GAE/g.

To test for significant differences between the mean values of islands and processors within each island, a series of univariate two-way nested ANOVA models was fitted to the data using SAS® OnDemand for Academics (SAS Institute Inc., 2024), with the significance threshold set at  $p < 0.01$ . Post hoc tests were performed following ANOVA to identify specific significant group differences ( $p < 0.05$ ) both

among islands and between processors within and across islands.

The ANOVA model followed the linear form:

$$y_{ijk} = \mu + Island_j + Processor_{k(j)} + e_i$$

where:

- $y_{ijk}$  represents the  $i^{\text{th}}$  observation from the  $j^{\text{th}}$  island and the  $k^{\text{th}}$  processor within the  $j^{\text{th}}$  island;
- $\mu$  is the overall mean;
- $Island_j$  is fixed the effect of the  $j^{\text{th}}$  island;
- $Processor_{k(j)}$  is the fixed effect of  $k^{\text{th}}$  processor within  $j^{\text{th}}$  island; and
- $e_i$  is the random error associated with the  $i^{\text{th}}$  observation.

Principal Component Analysis (PCA) was conducted using the `prcomp()` function in R software version 4.4.0 (R Core Team, 2024) to visualize data patterns within and across islands. A scree plot was generated to compare the variance explained by different principal components (PCs), and a two-dimensional PCA plot was created to illustrate the distribution patterns in the data. A correlation matrix was also generated in R to show the loadings of each variable on the PCs.

## Results and Discussion

The moisture content of *masmin* samples collected from the five islands showed significant variation, and the results are presented in Fig. 1a. Among these, samples from Kalpeni Island exhibited the lowest and highest recorded moisture contents of  $11.05 \pm 0.02\%$  and  $24.95 \pm 0.36\%$ , respectively. The Codex Alimentarius (Codex Standard 311–2013) recommends that the moisture content of smoked-dried fish should not exceed 10% to ensure the microbial safety of the product (Codex Alimentarius Commission, 2013). Consistent with this, previous studies have also suggested that the moisture level in smoke-dried fish should remain below 12% prior to storage, as higher moisture content may compromise both microbiological safety and overall product acceptability (Plahar, Nerquaye-Tetteh, & Annan, 1999; Daramola, Fasakin, & Adeparusi, 2007). In the present investigation, the average moisture content of *masmin* samples from the different islands varied

significantly ( $p < 0.05$ ), with values of  $16.21 \pm 2.10\%$  (Agatti),  $20.65 \pm 1.56\%$  (Amini),  $18.11 \pm 5.67\%$  (Kalpeni),  $16.91 \pm 2.41\%$  (Kavaratti), and  $14.76 \pm 1.29\%$  (Minicoy) (Fig. 2a). All the recorded values exceeded the recommended limits specified by the Codex Alimentarius and previous studies for ensuring the microbiological safety of smoke-dried fish. The observed variation in moisture content is likely attributable to differences in the duration of sun-drying, intensity of smoking, and other island-specific processing practices employed during *masmin* preparation.

In contrast to the present findings, Kingston, Rajagopalasamy, and Sugumar (1990) reported a much lower moisture content ( $6.20 \pm 0.14\%$ ) in traditional *masmin* obtained from the Tamil Nadu market, attributing the result to extended drying periods. Comparable research on *Katsuobushi*, which is a traditional Japanese product made from steamed, smoke-dried, and fermented skipjack tuna (*Katsuwonus pelamis*), has reported moisture levels similar to those observed in the present study. Nam et al. (2019) reported a moisture content of 18.0%, while Puspita (2020) observed values ranging from 15.4% to 16.1%. Conversely, Park et al. (2024) found a lower moisture content of  $11.24 \pm 1.42\%$  in *Katsuobushi* after 12 cycles of smoking and natural drying, consistent with the findings of Oh and Lee (1988), who reported 10–12% for powdered *Katsuobushi*.

Protein is the second most abundant component in the proximate composition of fish, following moisture (Ahmed & Sheikh, 2017). The crude protein content of *masmin* samples from five islands is shown in Fig. 1b and ranged between  $58.78 \pm 0.36\%$  and  $78.75 \pm 0.02\%$ , highlighting the exceptional nutritional value of traditionally smoke-dried tuna. The average crude protein content in *masmin* from different islands was significantly different ( $p < 0.05$ ), and found to be  $72.56 \pm 2.91\%$ ,  $66.91 \pm 1.80\%$ ,  $64.02 \pm 3.93\%$ ,  $68.83 \pm 5.06\%$ , and  $73.43 \pm 2.19\%$ , in Agatti, Amini, Kalpeni, Kavaratti, and Minicoy, respectively (Fig. 2b). The higher protein content is likely the result of lower moisture levels, indicating a concentration of essential nutrients as the water content decreases. To support this finding, Ahmed, Jan, Fatma, and Dawood (2022) observed that fish with lower moisture content typically exhibit higher protein concentrations, resulting in greater energy density.

Similar to the present investigation, high crude protein content has also been reported in other studies on smoke-dried fish products. Nam et al. (2019) found that *Katsubushi*, a Japanese smoke-dried product comparable to *masmin* of Lakshadweep, contained 69.3% crude protein. In line with this, Puspita (2020) reported a protein content ranging from 67.4% to 71.4% in smoke-dried skipjack tuna, further confirming the protein-rich nature of such traditional smoked products. Variations in protein content have also been observed in other smoked fish. Studies conducted by Gutema and Hailemichael (2021) and Mamun et al. (2024) reported protein content ranging from 62.0 to 73.7 g/100 g in dried small marine fish and related dried fish products. These results are consistent with the findings of Siddique and Aktar (2011), who also found protein content between 67.22% and 71.90% in the marine dried fish, *Lepturacanthus savala*.

The fat content of the *masmin* samples from five islands significantly differed within and between

the islands. The sample from Minicoy Island recorded the lowest fat content at  $1.35 \pm 0.03\%$ , whereas the highest fat content was observed in the sample from Kavaratti Island at  $7.96 \pm 0.18\%$  (Fig. 1c). In comparison, Nam et al. (2019) reported a higher lipid content of 7.7% in smoke-dried *katsubushi*. On the other hand, Puspita (2020) documented lower fat contents of 3.6% and 3.9% in smoke-dried skipjack, highlighting the variability of fat content in smoked fish products. Supporting this observation, Gutema and Hailemichael (2021) reported fat contents ranging from 2.89% to 8.60% in dried fish products from Ethiopia. Our observation of the drying process indicated that the products from Minicoy were dried for a longer duration, as reflected by the moisture values (Fig. 1a). During this process, the fat oozes out, resulting in lower fat content. To further support this, Afé et al. (2020) observed that variability in the lipid content of fish samples might be due to lipid loss during processing. In another study, Lawal and Alu (2024) reported

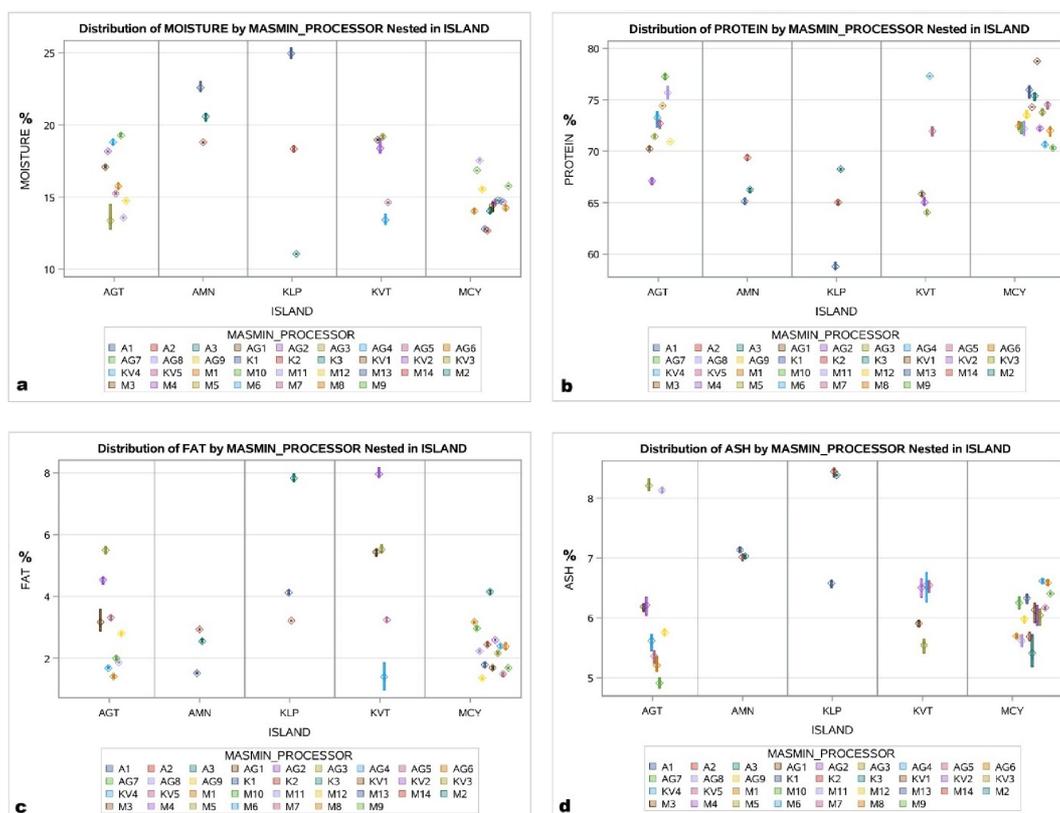


Fig. 1. Distribution of (a) moisture, (b) protein, (c) fat, and (d) ash in *masmin* samples processed by processors nested within each island

AGT-Agatti, AMN- Amini, KLP- Kalpeni, KVT- Kavaratti and MCY-Minicoy

AG- Agatti, A-Amini, K- Kalpeni, KV- Kavaratti and M-Minicoy

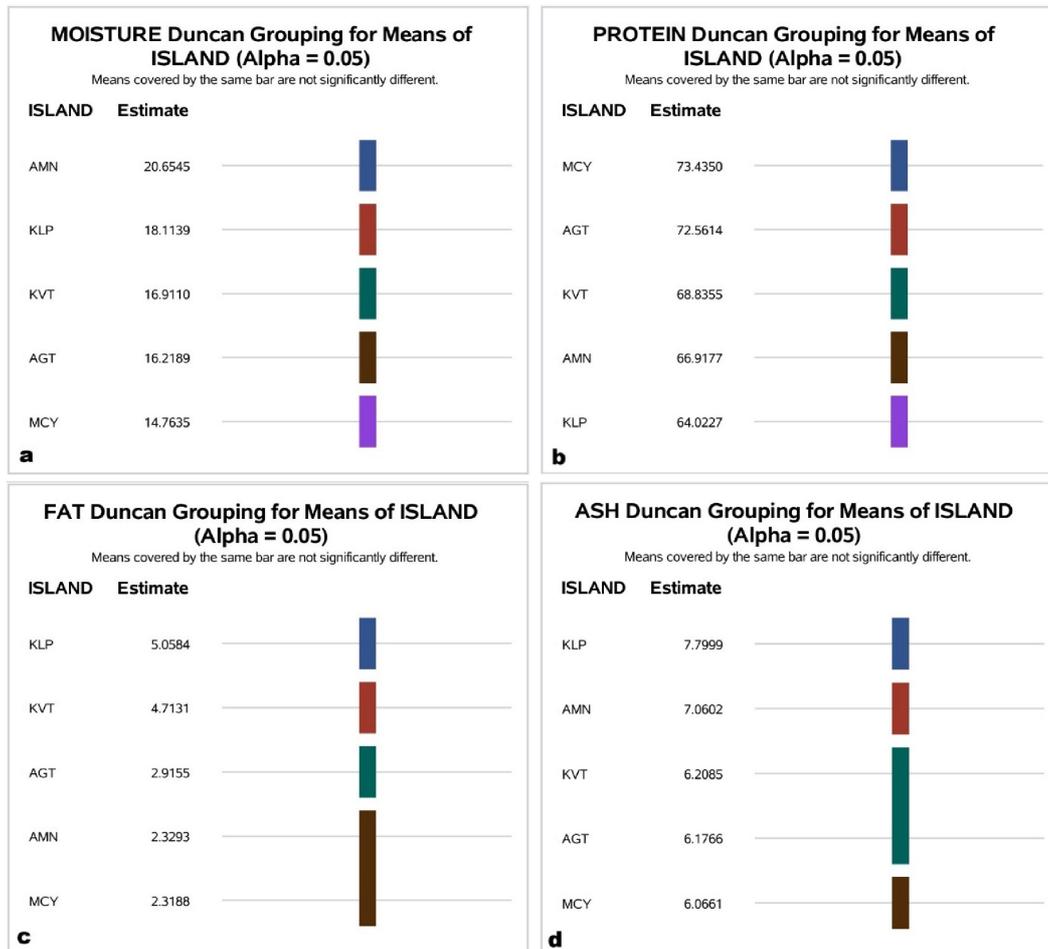


Fig. 2. Duncan grouping for means of Island: a) moisture, b) protein, c) fat, d) ash  
AGT-Agatti, AMN- Amini, KLP- Kalpeni, KVT- Kavaratti and MCY-Minicoy.  
Means covered by the same bar are not significantly different ( $\alpha=0.05$ )

a lipid content of 7.79% in smoke-dried African mud catfish. Similarly, Akinsola, Idowu, Akanbi, and Taiwo-Oshin (2018) reported a slightly higher value of 8.46% in smoke-dried catfish.

Measuring ash content is a widely accepted method for estimating the overall mineral content in fish products (Ahmed & Sheikh, 2017). In the present study, the mean ash content of *masmin* samples from Amini ( $7.06 \pm 0.06\%$ ), Kalpeni ( $7.79 \pm 0.86\%$ ), and Minicoy ( $6.06 \pm 0.36\%$ ) was found to be significantly different, while those from Agatti ( $6.17 \pm 1.13\%$ ) and Kavaratti ( $6.20 \pm 0.42\%$ ) did not vary much ( $p < 0.05$ ) (Fig. 2d). In our observation, the ash content of *masmin* samples is primarily attributed to the additional salt absorbed during the cooking of the tuna fillet and the presence of bones in the final products. Among the samples, Agatti had the lowest

ash content at  $4.91 \pm 0.08\%$ , whereas Kalpeni had the highest at  $8.44 \pm 0.07\%$  (Fig. 1d). Compared to these findings, Nam et al. (2019) reported lower values ranging from 3.4% to 3.5% in smoke-dried skipjack tuna. A study by Lawal and Alu (2024) reported an ash content of 6.69% in smoke-dried African mud catfish, while Akinsola et al. (2018) found 4.70% in smoke-dried catfish (*Clarias gariepinus*). These observations suggest that species type, processing techniques, and regional practices contribute to the differences in ash content.

Sodium chloride (% NaCl) content is one of the most important parameters in smoked and marinated products since it strongly influences flavour, water activity, and shelf life. Excessive or inadequate salt concentrations can affect consumer acceptability and microbial safety (Soliman, Arab, Edris, & Elrais,

2024). Table 3 and Fig. 3a show the salt content (% NaCl) of *masmin* samples from different locations. Among the samples, those from Agatti Island showed the lowest ( $3.13 \pm 0.08\%$ ) and highest salt ( $7.13 \pm 0.03\%$ ) content. Similarly, in a previous study, Muraleedharan and Valsan (1980) reported a higher percentage of salt content (7.6%) in traditional *masmin* from Lakshadweep. Fig. 3b shows the mean value of salt content of *masmin* from Agatti ( $4.26 \pm 1.10\%$ ), Amini ( $4.58 \pm 0.93\%$ ), Kalpeni ( $4.91 \pm 1.24\%$ ), Kavaratti ( $4.36 \pm 0.54\%$ ), and Minicoy ( $4.92 \pm 0.68\%$ ), and found that it varies significantly, except for Kalpeni and Minicoy ( $p < 0.05$ ). These variations in the salt content of *masmin* can be attributed to differences in processing methods, particularly the ratio of seawater to freshwater used, the amount of common salt added during cooking, and the duration of cooking and drying. This observation was further supported by the findings of Valsan, Kandoran, and Rao (1964), who concluded that the water is reused multiple times, up to eight cycles, for cooking fresh batches until it thickens into a concentrated form, thereby increasing the salt content of the broth. Extending support for this observation, Naila et al. (2011) found that cooked tuna loins absorb a high amount of salt during the cooking process and found moderate salt content of 1.4–1.6% in *Rihaakru*, a concentrated form of cooked broth. During our observations, we found that each *masmin* processor used a different ratio of seawater to freshwater and salt, leading to different salt levels in the final product. It is also evident from the present investigation that the higher the salt content, the lower the moisture, corresponding to longer

drying. To further support the findings, the PCA biplot also shows divergent arrows for salt and moisture (Fig. 6a). Several other studies have also reported variation in salt content in smoked and dried fish. Compared to the present investigation, Fuentes, Fernández Segovia, Barat, and Serra (2010) recorded a lower salt content of 2.91% in smoked tuna from supermarkets of Valencia, Spain. However, Karaskova et al. (2011) reported moderate salt contents of 2.98–6.55% and 3.34–4.15% in smoked cod and salmon, respectively. In another study, Soliman et al. (2024) observed a relatively higher salt content of 6.33% in smoked herring.

Table 3 presents the pH levels of the *masmin* samples. The lowest pH value ( $5.48 \pm 0.01$ ) was recorded in the sample from Kalpeni Island, while the highest ( $7.37 \pm 0.00$ ) was found in the sample from Kavaratti Island. The mean pH values of *masmin* from different islands were significantly different ( $p < 0.05$ ), with the following averages: Agatti ( $6.04 \pm 0.51$ ), Amini ( $6.62 \pm 0.64$ ), Kalpeni ( $5.79 \pm 0.41$ ), Kavaratti ( $6.46 \pm 0.64$ ), and Minicoy ( $5.73 \pm 0.06$ ) (Fig. 4). The fish processed in these islands were generally in a very fresh condition, mostly within 2–3 hours of capture, likely during the rigor mortis period. Therefore, the relatively low pH values ( $5.73 \pm 0.06$  to  $6.62 \pm 0.64$ ) are not unexpected. The lower pH of smoked products is consistent with the findings of Yu et al. (2023), who observed that smoked *katsuobushi* from Japan exhibited a lower pH than raw tuna, attributing this to the decomposition of glycogen, ATP, and phosphocreatine in tuna muscle during smoking. Similarly, Soliman et al.

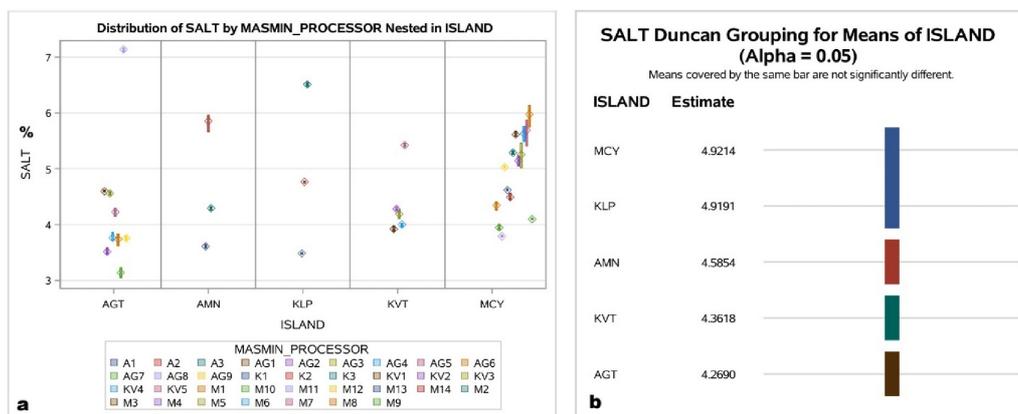


Fig. 3. a) Distribution of salt (% NaCl) in *masmin* samples processed by processors nested in an island b) Salt (% NaCl) DUNCAN grouping for means of island ( $\alpha = 0.05$ )

AGT-Agatti, AMN- Amini, KLP- Kalpeni, KVT- Kavaratti and MCY- Minicoy  
 AG- Agatti, A-Amini, K- Kalpeni, KV- Kavaratti and M-Minicoy

(2024) reported a pH of 6.18 for smoked herring. In another study, Afé et al. (2020) recorded a pH of 6.4 in smoked *Scomber scombrus* produced in South Benin, which closely aligns with the pH 6.1 reported by Kiczorowska, Samolinska, Grela, and Bik-Małodzinska (2019) for the same species smoked in Poland. Conversely, Assogba et al. (2022) found that smoke-drying fish without prior salting increased pH, with values rising from 6.2 in fresh flying fish to 6.8 after smoke-drying. Regarding sun-dried fish, Ullah, Hazarika, and Handique (2016) reported pH values ranging from 6.23 to 8.33 in ten dried fish samples from Northeast India. Similarly, Kumar et al. (2017) observed that salted, sun-dried fish generally exhibit lower pH levels than unsalted, dried *Pangasius hypophthalmus*.

Phenolics and flavonoids are well-known bioactive compounds produced during the smoking process that play an essential role in preserving and improving the organoleptic properties of smoked products (Abdel-Naeem, Sallam, & Malak, 2021). The distribution of TPC in 34 *masmin* samples from five different islands is given in Fig. 5a, and the results are expressed as mg Gallic Acid Equivalent (GAE)/g of *masmin*. The mean values of TPC in the *masmin* samples from Agatti (11.47 ± 1.85), Amini (8.78 ± 1.21), and Minicoy (13.34 ± 1.98) were significantly different ( $p < 0.05$ ), except for Kalpeni (10.14 ± 2.51) and Kavaratti (10.21 ± 2.47) (Fig. 5b).

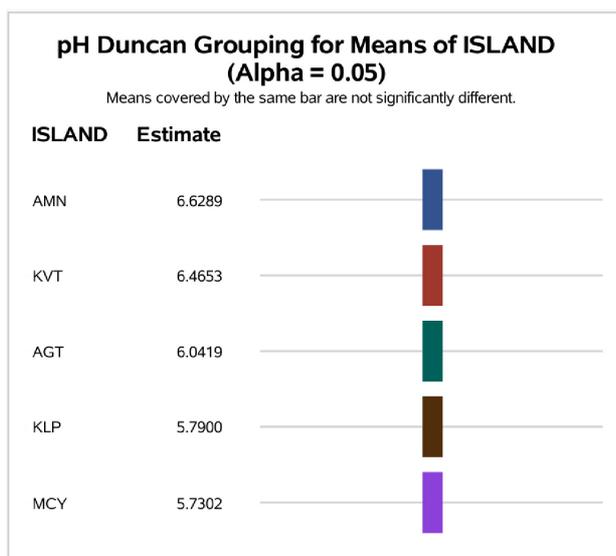


Fig. 4. pH Duncan grouping for means of Island AGT-Agatti, AMN- Amini, KLP- Kalpeni, KVT- Kavaratti and MCY- Minicoy

The concentration of phenolic compounds in smoked products depends on the smoking method, duration, temperature, and type of wood used (Guillen & Manzanos, 1996). Coconut husks are the primary fuel source for smoke generation in Lakshadweep Islands and are rich in lignin (33%) (Pollard, Fowler, Sollars, & Perry, 1992). Further pyrolysis of lignin forms phenols and phenolic esters (Maga, 2018). The mean TPC values (Fig. 5b) and PCA biplot (Fig. 6a) show that TPC is inversely proportional to moisture and directly proportional to salt. In the present investigation, the highest TPC of 16.51 ± 0.34 mg GAE/g was observed in the sample from Minicoy Island, and the lowest was observed in the sample from Kavaratti Island (6.78 ± 0.91). As described earlier, Minicoy had a longer drying time, reducing the moisture, increasing the salt, and requiring longer smoking duration. Longer smoking time, apart from proportional changes in mass due to reduced moisture content, must have resulted in higher TPC. In comparison with the present investigation, Antony et al. (2003) reported a much lower phenolic content of 1.9 mg/100 g in laboratory-prepared *masmin* made from mackerel tuna smoked for one hour at a temperature range of 55–60 °C, using sawdust from non-resinous wood as the fuel source. In contrast, Kingston et al. (1990) reported total phenolics of 23.56 and 10.50 mg/100 g in mechanically kiln-prepared and traditional *masmin*, respectively. These differences can be attributed to variations in preparation techniques, particularly differences in smoking duration practiced by different *masmin* processors, which significantly affect the final phenolic content in the samples. In another study, Tiwo et al. (2018) reported a total phenolic content (TPC) of 2.12–4.64 mg/100 g in smoked fish using the wood of *Rhizophora mangle*. However, according to Albishi, Banoub, de Camargo, and Shahidi (2019), the TPC of dried extracts of date palm and maple wood were 73.48 and 52.27 mg GAE/g, respectively, and they found that date palm wood is a good source of phenolics for smoking salmon. The estimated TPC of commercial liquid smoke and liquid smoke prepared from coconut husk, coconut fibre, and coconut fibre powder were 20047, 1518, 1037, and 834 mg GAE/L, respectively (Nithin et al., 2020).

Fig. 6a shows the Principal Component Analysis (PCA) biplot, a multivariate data visualization method used to reduce the dimensionality of complex datasets while preserving as much variability as possible. The horizontal axis explains 44.97%

Table 3. Salt and pH of the *Masmin* from Lakshadweep

Sl. No.	Sample Name	Salt (% NaCl)	pH
1	Agatti-1	4.59 ± 0.01 <sup>e</sup>	6.69 ± 0.00 <sup>h</sup>
2	Agatti-2	3.51 ± 0.05 <sup>b</sup>	7.21 ± 0.00 <sup>i</sup>
3	Agatti-3	4.55 ± 0.02 <sup>e</sup>	5.70 ± 0.00 <sup>c</sup>
4	Agatti-4	3.76 ± 0.08 <sup>c</sup>	5.75 ± 0.00 <sup>e</sup>
5	Agatti-5	4.22 ± 0.07 <sup>d</sup>	5.67 ± 0.00 <sup>b</sup>
6	Agatti-6	3.73 ± 0.10 <sup>c</sup>	5.88 ± 0.01 <sup>f</sup>
7	Agatti-7	3.13 ± 0.08 <sup>a</sup>	6.06 ± 0.01 <sup>g</sup>
8	Agatti-8	7.13 ± 0.03 <sup>f</sup>	5.66 ± 0.01 <sup>a</sup>
9	Agatti-9	3.75 ± 0.02 <sup>c</sup>	5.73 ± 0.00 <sup>d</sup>
10	Amini-1	3.60 ± 0.02 <sup>a</sup>	7.34 ± 0.00 <sup>c</sup>
11	Amini-2	5.85 ± 0.16 <sup>c</sup>	5.77 ± 0.00 <sup>a</sup>
12	Amini-3	4.44 ± 0.07 <sup>b</sup>	6.76 ± 0.01 <sup>b</sup>
13	Kalpeni-1	3.48 ± 0.01 <sup>a</sup>	6.37 ± 0.00 <sup>c</sup>
14	Kalpeni-2	4.76 ± 0.01 <sup>b</sup>	5.48 ± 0.01 <sup>a</sup>
15	Kalpeni-3	6.50 ± 0.02 <sup>c</sup>	5.51 ± 0.00 <sup>b</sup>
16	Kavaratti-1	3.91 ± 0.04 <sup>a</sup>	6.13 ± 0.01 <sup>b</sup>
17	Kavaratti-2	4.27 ± 0.02 <sup>d</sup>	7.37 ± 0.00 <sup>e</sup>
18	Kavaratti-3	4.18 ± 0.07 <sup>c</sup>	7.02 ± 0.01 <sup>d</sup>
19	Kavaratti-4	4.00 ± 0.07 <sup>b</sup>	6.21 ± 0.00 <sup>c</sup>
20	Kavaratti-5	5.42 ± 0.02 <sup>e</sup>	5.58 ± 0.00 <sup>a</sup>
21	Minicoy-1	4.34 ± 0.07 <sup>c</sup>	5.81 ± 0.01 <sup>h</sup>
22	Minicoy-2	5.28 ± 0.02 <sup>f</sup>	5.71 ± 0.00 <sup>cd</sup>
23	Minicoy-3	5.61 ± 0.05 <sup>g</sup>	5.70 ± 0.00 <sup>c</sup>
24	Minicoy-4	5.14 ± 0.08 <sup>ef</sup>	5.75 ± 0.00 <sup>f</sup>
25	Minicoy-5	5.25 ± 0.22 <sup>f</sup>	5.75 ± 0.00 <sup>f</sup>
26	Minicoy-6	5.62 ± 0.13 <sup>g</sup>	5.77 ± 0.00 <sup>g</sup>
27	Minicoy-7	5.68 ± 0.24 <sup>g</sup>	5.75 ± 0.00 <sup>f</sup>
28	Minicoy-8	5.97 ± 0.19 <sup>h</sup>	5.73 ± 0.00 <sup>e</sup>
29	Minicoy-9	4.09 ± 0.01 <sup>b</sup>	5.81 ± 0.00 <sup>h</sup>
30	Minicoy-10	3.94 ± 0.04 <sup>ab</sup>	5.77 ± 0.00 <sup>g</sup>
31	Minicoy-11	3.78 ± 0.01 <sup>a</sup>	5.73 ± 0.00 <sup>e</sup>
32	Minicoy-12	5.02 ± 0.01 <sup>e</sup>	5.58 ± 0.00 <sup>a</sup>
33	Minicoy-13	4.61 ± 0.01 <sup>d</sup>	5.60 ± 0.00 <sup>b</sup>
34	Minicoy-14	4.48 ± 0.06 <sup>cd</sup>	5.71 ± 0.00 <sup>d</sup>

Mean ± S.D values bearing different superscripts between samples are significantly different at  $p < 0.05$ .

of the total variance in the data, and the vertical axis explains 25.30% of the total variance. Together, these two principal components explain a significant portion (over 70%) of the variability in the dataset. The arrows represent different variables measured across samples, including moisture, pH, fat, ash, salt, total phenolic content, and protein. The length and direction of the arrows indicate that longer

arrows represent stronger contributions of a variable to the principal components. Arrows pointing in the same direction are positively correlated, while arrows at an angle close to 90° are uncorrelated, and arrows pointing in opposite directions are negatively correlated. Different islands (Agatti, Amini, Kalpeni, Kavaratti, and Minicoy) are represented by color-coded ellipses and points, each corresponding

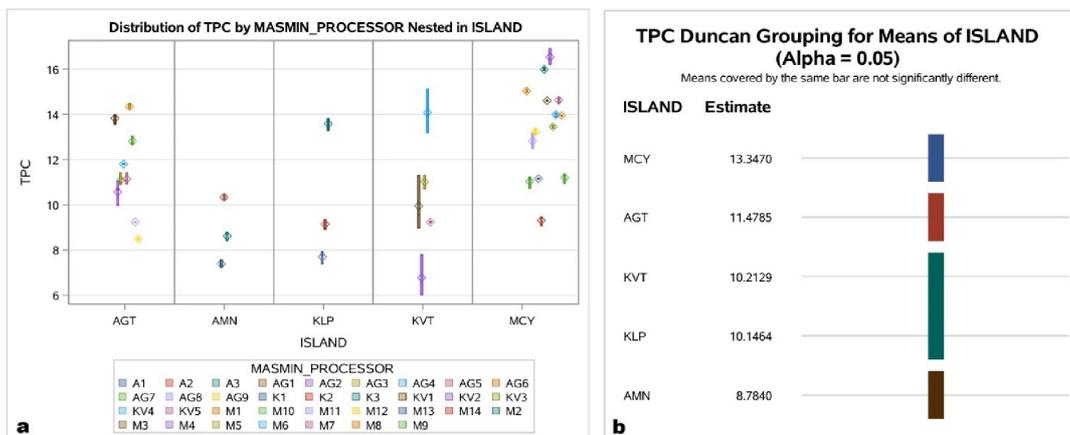


Fig. 5. a) Distribution of TPC by *masmin* processors nested within an island b) TPC DUNCAN grouping for Means of Islands

AGT-Agatti, AMN- Amini, KLP- Kalpeni, KVT- Kavaratti and MCY-Minicoy

AG- Agatti, A-Amini, K- Kalpeni, KV- Kavaratti and M-Minicoy

Principal components analysis (PCA)

to a specific sample grouping. The ellipses represent the confidence intervals for the groupings, indicating where the majority of samples from each island lie. The groups of samples from different islands show distinct separation in some cases, with Kalpeni (KLP, green) being particularly distinct from the others. This suggests that samples from KLP have different characteristics compared to those from other islands. Amini (AMN, yellow) and Agatti (AGT, red) show some overlap, indicating potential similarities in the composition of samples from these islands. Kavaratti (KVT, blue) and Minicoy (MCY, purple) also overlap slightly but are separated from KLP and AGT.

Salt and ash have long arrows pointing in the same general direction, suggesting that they are strongly correlated and contribute similarly to the variance in the data. Protein and fat are also correlated, as their arrows are closely aligned, indicating that as one increases, the other likely increases as well. Moisture is positioned opposite to protein, suggesting a negative correlation between them. This means samples with lower moisture content have higher protein content. The spread of the data points within each island grouping (e.g., the wide spread of Kalpeni compared to the more tightly grouped Minicoy) indicates the degree of variability within each group. Some points, particularly from the Kalpeni group, are farther from the centre, suggesting more diverse samples from that island compared to others. There is a clear separation between

sample groups from different islands, particularly Kalpeni, which appears to have distinct properties. Variables such as salt, ash, fat, and protein are strong contributors to the principal components, with moisture showing an inverse relationship with protein. The PCA biplot effectively captures over 70% of the variations in the data, highlighting distinct groupings and key variable relationships. This plot provides useful insights into how different island samples compare based on their compositional attributes, as well as how the samples within each island vary with respect to these parameters.

*Masmin* is the traditional smoke-dried tuna from Lakshadweep and supports the protein needs of over 65,000 islanders in the Indian Ocean. Analysis of *masmin* samples from different islands showed significant variability in proximate composition. These differences have most likely resulted from unique local practices and variations in the smoking process among the islands. The length of drying, reflected in the moisture content, showed variations from 11.05 to 24.95%. Samples from Minicoy generally had lower moisture levels, which could enhance their shelf life, as lower moisture reduces susceptibility to spoilage. In contrast, Kalpeni samples exhibited higher moisture content, suggesting shorter or less intensive smoking and drying. Protein content remained consistently high among the samples, highlighting the nutritional value of *masmin*. The variation in protein content and TPC appeared to be influenced by the smoking and

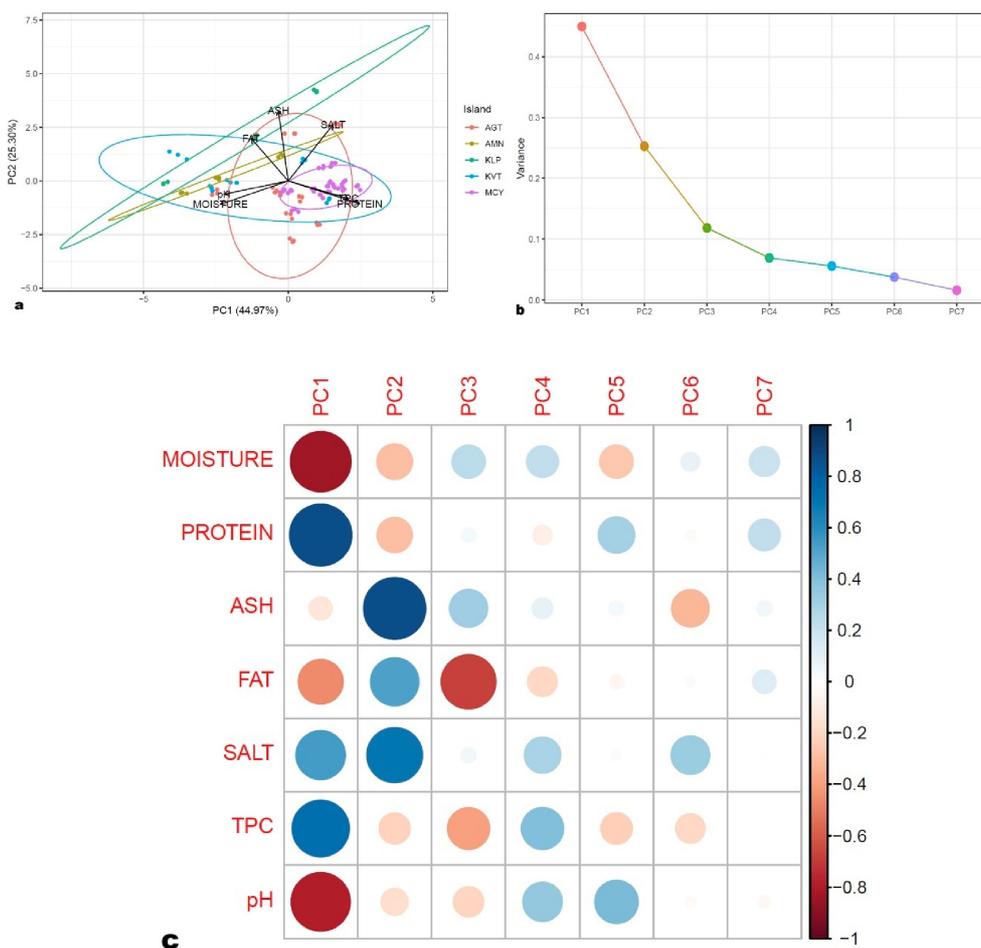


Fig. 6. a) Principal component analysis (PCA) biplot and b) Scree plot of the variance explained by different principal components (PCs). c) Correlation matrix

AGT-Agatti, AMN- Amini, KLP- Kalpeni, KVT- Kavaratti, and MCY- Minicoy

drying practices in different islands. Generally, among the islanders, it is perceived that Minicoy *masmin* keeps better, lasts longer, and is preferred. However, our observation shows that they are much drier, have higher TPC and salt content, all of which contribute to their keeping quality. The higher protein content is likely due to moisture loss during drying. The variability in salt and pH levels across different islands likely reflects local practices such as curing duration, salting methods, and drying conditions. All the data with respect to pH, salt, and protein showed significant variations within as well as among the islands. Analysis of the TPC in the *masmin* samples across various islands also indicated significant variation. This study emphasizes the potential for optimizing smoking techniques to enhance the overall quality of traditionally prepared *masmin* products.

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