



Physicochemical, Microbial and Sensory Dynamics of Traditionally Smoked and Dried Zig-zag Eel (*Mastacembelus armatus*) from an Open Market in Chhattisgarh under Different Storage Conditions

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ABSTRACT

Background: Traditional fish processing methods such as smoking and drying are widely practiced in rural regions; however, limited scientific information is available regarding the quality stability of these products under different storage conditions. This study aimed to evaluate the physicochemical, microbial and sensory changes in traditionally smoked and dried zig-zag eel (*Mastacembelus armatus*) obtained from open market in Chhattisgarh during storage under ambient and refrigerated conditions.

Methods: Smoked and dried eel samples were collected from the Kawardha fish market and stored for 30 days under ambient and refrigerated conditions. Analyses were conducted on days 0, 15 and 30. Proximate composition (moisture, protein, lipid and ash), biochemical parameters (total volatile base nitrogen, peroxide value and free fatty acids), microbial load (total plate count) and sensory attributes were evaluated using standard methods.

Result: During storage, moisture content increased, while protein, lipid and ash contents decreased in both smoked and dried samples, with more pronounced changes under ambient conditions. Spoilage indicators, including total volatile base nitrogen, peroxide value and free fatty acids, showed progressive increases over time, indicating progressive deterioration. Microbial analysis revealed that total plate count exceeded acceptable limits (>5 log CFU/g) in dried samples under both storage conditions, whereas smoked samples remained within acceptable levels. Sensory scores declined throughout the storage period, particularly under ambient conditions. Refrigerated storage slowed physicochemical degradation, microbial growth and sensory deterioration, thereby better preserving the overall quality of the products during the 30-day storage period.

Key words: Dried fish, Refrigerated storage, Smoked fish, Storage study.

INTRODUCTION

The preservation of fish through traditional methods such as smoking and drying remains widely practiced in many parts of India, particularly in rural and tribal communities where refrigeration infrastructure is limited (Panda *et al.*, 2022). Among the various freshwater species utilized for such processing, *Mastacembelus armatus*, commonly known as the zig-zag eel or spiny eel (Serajuddin *et al.*, 1998; Hossain *et al.*, 2015; Yang *et al.*, 2024a), holds significant economic and nutritional importance in the inland fisheries sector of Chhattisgarh. The species is locally preferred and is commonly available in traditionally smoked and dried forms in the open markets of the region, making it an important component of the local traditional fish trade. Its firm texture, high protein content and palatability further contribute to its consumer acceptance (Yang *et al.*, 2024b). These characteristics distinguish *M. armatus* from many commercially important fishes that are predominantly traded in fresh or other processed forms and highlight its relevance for evaluating the quality and storage stability of traditionally smoked and dried fish products.

Traditional smoking and drying techniques, typically performed without standardized protocols, are employed

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to extend shelf life, reduce post-harvest losses and enhance flavor (Geraldo *et al.*, 2024). Previous studies have

also demonstrated that the quality of traditionally processed fish can vary considerably with processing conditions, with differences observed in physicochemical, microbiological and sensory characteristics (Jakhar *et al.*, 2018; Payra *et al.*, 2025). However, these artisanal methods often lack scientific validation in terms of quality and safety under various storage environments.

Fish products are highly perishable due to their high moisture content, enzymatic activity and susceptibility to microbial spoilage (Nie *et al.*, 2022). Although smoking and drying reduce water activity and inhibit microbial growth (Pittia and Antonello, 2016), these preservation techniques do not entirely eliminate spoilage risks, especially when storage conditions are suboptimal. Over time, physicochemical changes such as lipid oxidation, protein denaturation and textural degradation may occur, adversely affecting product quality (Suárez-Medina *et al.*, 2024). Furthermore, microbial growth can continue to progress during storage, particularly under ambient conditions, compromising both safety and sensory acceptability (Sheng and Wang, 2021).

Recent studies have emphasized the effects of processing and storage conditions on the quality and shelf life of smoked and dried fish. For example, Bolaji *et al.* (2026) reported changes in biochemical and sensory quality parameters of smoked catfish during storage, highlighting the influence of smoking conditions on subsequent product quality and acceptability. Similarly, Salami *et al.* (2024) evaluated smoked and oven-dried *Clarias gariepinus* during storage and reported progressive quality deterioration and microbiological changes. Jakhar *et al.* (2025) investigated traditionally smoked and dried *Salmophasia bacaila* for 30 days under ambient and refrigerated conditions and observed progressive changes in proximate composition, spoilage indices, microbial load and sensory quality. Obugara *et al.* (2026) evaluated smoke-cured *C. gariepinus* over 28 days of storage and reported declines in sensory and protein quality accompanied by increased lipid oxidation and microbial load. Similarly, Sulfiana *et al.* (2026) assessed traditionally smoked *Rastrelliger kanagurta* for 6 days under ambient conditions and documented increases in TVB-N, PV, FFA and microbial counts. These findings highlight the important role of storage duration and conditions in determining the quality and shelf-life of smoked and dried fish products.

The open markets of Chhattisgarh serve as key distribution points for traditionally processed fish, yet limited information is available on the storage quality of traditionally smoked and dried *M. armatus* obtained from these markets. Although previous studies have examined the storage stability of various smoked and dried fish products, the comparative changes in nutritional composition, biochemical spoilage indicators, microbial quality and sensory attributes of traditionally processed *M. armatus* under contrasting ambient and refrigerated conditions

remain insufficiently documented. This constitutes an important research gap, as storage conditions can substantially influence physicochemical deterioration, microbial proliferation and sensory quality loss in traditionally processed fish products. Therefore, evaluating the physicochemical, microbial and sensory parameters of smoked and dried fish under different storage conditions is critical for ensuring consumer safety and promoting standardized post-processing practices. Parameters such as proximate composition, biochemical parameters (such as TVB-N, FFA and PV), microbial load and sensory characteristics provide comprehensive insights into product stability over time (Jakhar *et al.*, 2025).

Therefore, the present study was designed to address this gap by providing an integrated assessment of the quality changes in traditionally smoked and dried *M. armatus* obtained from the Chhattisgarh open market and stored under ambient and refrigerated conditions for 30 days. The novelty of the study lies in its focused evaluation of proximate composition, biochemical spoilage indicators (TVB-N, FFA and PV), microbial load and sensory attributes of traditionally smoked and dried *M. armatus* under these two contrasting storage conditions. Such information can provide a scientific basis for improving storage and handling practices and supporting quality assurance among processors and vendors of traditionally processed *M. armatus*.

MATERIALS AND METHODS

Sample collection, packaging and storage conditions

The study was carried out from mid-March to mid-April 2025 at the Department of Fish Harvest and Post-Harvest Technology, LSPN College of Fisheries, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Kawardha, Chhattisgarh, India. Dried and smoked samples of eel (*M. armatus*) (1000 g each) were collected from a single local fish vendor at the Kawardha fish market in Chhattisgarh, India (Fig 1). The samples were aseptically packed in clean zip-lock plastic pouches and transported to the laboratory. Each sample was divided into two equal portions (500 g), with one portion stored under ambient conditions (20-40°C) and the other under refrigerated conditions (4±1°C). Ambient temperature was not continuously monitored during the storage period; therefore, the stated range represents the prevailing ambient storage conditions rather than a controlled or constant temperature. The samples were protected from direct sunlight and exposed only to normal indoor/artificial light during the storage period. Relative humidity was not artificially controlled and remained at the prevailing storage-room conditions. Samples were analyzed on the 0th, 15th and 30th days.

Proximate composition analysis

The sample's proximate composition, including moisture, protein, lipid and ash, was assessed using standard

methods outlined in AOAC (2005). The results were reported as g/100 g (wet weight basis).

Biochemical analysis

The estimation of total volatile base nitrogen (TVB-N), peroxide value (PV) and free fatty acids (FFA) were carried out following the standard procedures outlined by the association of official analytical chemists (AOAC, 2005).

Microbial analysis

The microbial quality of the samples, specifically the total plate count (TPC), was assessed according to the protocols described in the bacteriological analytical manual (BAM, 2024) with modification. Briefly, 5 g of each sample was homogenized with 45 mL of sterile physiological saline solution to obtain the initial dilution. Serial tenfold dilutions were then prepared up to 10^{-5} by transferring 1 mL of the previous dilution into 9 mL of sterile physiological saline under aseptic conditions. From each dilution, 0.1 mL was spread onto plate count agar plates and incubated at 37°C for 18-24 h. Colony-forming units (CFUs) were enumerated and results were expressed as log CFU/g of the sample.

Sensory analysis

The sensory evaluation of the samples was carried out by a semi-trained panel consisting of 20 members, including students and faculty from LSPN College of Fisheries, Kawardha, who were accustomed to consuming smoked and dried fish. The panelists, selected based on their familiarity with such products, assessed the organoleptic qualities of the samples. The samples were served on clean plates under hygienic conditions. Sensory attributes such as color, odor, texture, appearance and overall acceptability were evaluated using a 9-point hedonic scale, following the method outlined by Das *et al.* (2023) and Kumar *et al.* (2026). Participation was voluntary and verbal informed consent was obtained from all panelists prior to their participation in the sensory evaluation.

Statistical analysis

Statistical analysis was conducted for only proximate composition data, for which three separate portions were taken from the original sample and analyzed independently. The results are presented as mean $\pm$ standard deviation (SD; $n=3$). Duncan's multiple range test (DMRT) was applied to determine statistically significant differences among storage days (0, 15 and 30 days) within each storage treatment at a significance level of $p<0.05$. Statistical analyses were conducted using Microsoft Excel 2019 and SPSS software (version 23.0).

Statistical analysis was not performed for biochemical and microbial data because only one biological sample was used for the analysis, although the biochemical analyses were performed in triplicate and the microbial analysis was performed in duplicate. For TVB-N, PV and FFA, triplicate titrations were first averaged and then used

to calculate a single value per sample, while for TPC, duplicate plate counts were averaged to determine microbial load. As these measurements do not represent independent biological observations, ANOVA was not applicable. Accordingly, variability estimates such as standard deviation and corresponding error bars are not presented for these parameters and the results are interpreted descriptively. Graphs and radar charts were plotted using Origin Pro 2025.

RESULTS AND DISCUSSION

Changes in proximate composition

The proximate composition of smoked and dried eel is summarized in Table 1. On day 0, the moisture, protein, lipid and ash contents of the dried eel were 13.1%, 58.2%, 14.2% and 11.2%, respectively. Correspondingly, the smoked eel exhibited moisture, protein, lipid and ash contents of 15.3%, 53.4%, 13.5% and 12.5%, respectively. During storage, an increasing trend in moisture content was observed, while the levels of protein, lipid and ash exhibited a gradual decline over time.

Moisture

Smoking and drying are traditional preservation methods aimed at lowering the moisture content of fish to levels that inhibit microbial proliferation and spoilage. In the present investigation, the initial moisture content of eel subjected to drying and smoking was recorded at 13.1% and 15.3%, respectively. Over the course of storage, both products exhibited a progressive increase in moisture content. After 30 days, the moisture level in dried eel increased significantly under ambient conditions, reaching 17.5% ($p<0.05$), while under refrigerated storage it rose to 14.0% ($p>0.05$). In smoked eel, moisture content similarly increased to 16.3% under ambient storage and 16.2% under refrigeration, with both changes being statistically non-significant ($p>0.05$). The progressive changes in

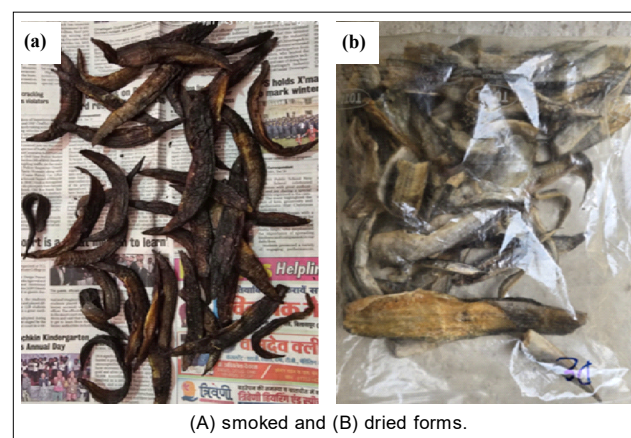


Fig 1: Images of eel (*M. armatus*) samples collected from local fish vendor at kawardha fish market in Chhattisgarh.

moisture content during storage may be related to the different forms of water present in fish muscle. Fish muscle contains bound and free water, with free water showing greater mobility and being more readily lost during drying, thereby contributing to the reduction in moisture content (Andersen and Rinnan, 2002; da Silva Carneiro *et al.*, 2016). Following drying, the low-moisture product may absorb atmospheric moisture during storage when a moisture gradient exists between the fish and the surrounding environment. This moisture migration may be greater under ambient conditions, resulting in greater moisture uptake than under refrigeration. Increased moisture availability may subsequently favour microbial growth and accelerate quality deterioration (Fitri *et al.*, 2022). These findings are consistent with earlier studies that have documented similar trends of moisture uptake during storage of smoked and dried fish products (Ikutegbe and Sikoki, 2014; Farid *et al.*, 2014; Ayeloja *et al.*, 2020). The hygroscopic nature of dried fish products may further contribute to moisture absorption during storage (Olayemi *et al.*, 2015).

Protein

On day 0, the protein content in dried and smoked eel was recorded at 58.2% and 53.4%, respectively. This high protein concentration is primarily attributed to moisture reduction during the drying and smoking processes, which leads to protein densification and aggregation (Linus-Chibuezeh *et al.*, 2022). Over the storage period, a gradual decline in protein content was evident in both product types. In dried eel, protein levels decreased to 55.2% under ambient conditions ($p<0.05$) and to 55.8% under refrigerated storage ($p<0.05$). Similarly, smoked eel exhibited a reduction in protein content to 52.4% at ambient temperature ($p<0.05$) and 52.6% under refrigeration ($p>0.05$). These patterns align with previous reports indicating a progressive decline in protein content in smoked-dried and sun-dried fish during storage (Farid *et al.*, 2014; Ikutegbe and Sikoki, 2014; Jakhar *et al.*, 2025).

The observed decrease is likely associated with the leaching of water-soluble protein fractions and the degradation of protein molecules into volatile nitrogenous compounds, including total volatile bases (TVB), ammonia and hydrogen sulfide (Daramola *et al.*, 2007; Ikutegbe and Sikoki, 2014; Ayeloja *et al.*, 2020).

Lipid

A progressive reduction in lipid content was noted in both smoked and dried eel samples throughout the storage duration. In the dried eel, lipid concentration declined from an initial value of 14.2% to 11.7% under ambient conditions ($p<0.05$) and to 13.2% during refrigerated storage ($p<0.05$). Similarly, smoked samples exhibited a decrease in lipid content from 13.5% to 11.8% at ambient temperature ($p<0.05$) and to 12.3% under refrigeration ($p<0.05$). This reduction in lipid levels over time is likely due to lipid degradation processes, particularly oxidative rancidity and hydrolysis of susceptible lipid fractions, which are known to occur during the storage of fish products (Daramola *et al.*, 2007; Farid *et al.*, 2014; Ikutegbe and Sikoki, 2014; Ayeloja *et al.*, 2020). The greater reduction under ambient conditions indicates accelerated lipid degradation at higher temperatures, whereas refrigeration slowed these reactions and favoured better lipid retention. The observed decline is also consistent with the increases in PV and FFA recorded in the present study, indicating progressive lipid deterioration during storage.

Ash

The initial ash content was relatively high in both dried and smoked eel samples, recorded at 11.2% and 12.5%, respectively. Elevated ash levels in dried fish products have similarly been reported in previous studies (Rana *et al.*, 2020), likely reflecting the concentration of mineral components following moisture removal. Over the storage period, a gradual decline in ash content was observed in both treatments; however, the reduction was not statistically significant ($p>0.05$). In the case of dried eel stored at

Table 1: Proximate composition of dried and smoked *M. armatus* stored at ambient and refrigerated temperatures on 0th, 15th and 30th day.

Process	Storage temp.	Day	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)
Dried	Ambient	0	13.1±0.7 ^a	58.2±0.7 ^b	14.2±0.5 ^b	11.2±0.6 ^a
		15	15.3±0.3 ^b	57.3±0.4 ^b	12.9±1.0 ^{a, b}	11.0±1.6 ^a
		30	17.5±0.3 ^c	55.2±0.6 ^a	11.7±0.3 ^a	10.9±0.2 ^a
Dried	Refrigerated	0	13.1±0.7 ^a	58.2±0.7 ^b	14.2±0.5 ^b	11.2±0.6 ^a
		15	14.3±0.9 ^a	57.9±0.1 ^b	13.7±0.2 ^{a, b}	11.1±0.5 ^a
		30	14.0±0.6 ^a	55.8±0.6 ^a	13.2±0.2 ^a	11.0±0.5 ^a
Smoked	Ambient	0	15.3±1.0 ^a	53.4±0.2 ^b	13.5±0.3 ^b	12.5±0.6 ^a
		15	15.8±0.9 ^a	52.6±0.2 ^a	12.5±0.5 ^{a, b}	12.3±0.9 ^a
		30	16.3±0.1 ^a	52.4±0.2 ^a	11.8±0.7 ^a	11.9±0.6 ^a
Smoked	Refrigerated	0	15.3±1.0 ^a	53.4±0.2 ^a	13.5±0.3 ^b	12.5±0.6 ^a
		15	15.2±0.6 ^a	53.1±0.6 ^a	13.2±0.3 ^b	12.2±0.8 ^a
		30	16.2±0.3 ^a	52.6±0.4 ^a	12.3±0.1 ^a	12.1±0.4 ^a

Values are expressed as mean±SD (n=3). Within each storage treatment, means bearing different superscript letters across storage days are significantly different ($p<0.05$), whereas means sharing a common superscript letter are not significantly different ($p>0.05$).

ambient conditions, ash content decreased marginally from 11.2% to 10.9%, whereas under refrigerated conditions, it reduced to 11.0% ($p>0.05$). Similarly, in smoked eel, ash content showed a slight decline from 12.5% to 11.9% at ambient temperature and to 12.1% under refrigeration, with no significant differences observed ($p>0.05$). These observations are consistent with the trends reported by Olayemi *et al.* (2015). The relatively small changes in ash content suggest that mineral constituents remained comparatively stable during storage.

Biochemical changes

Total volatile base-nitrogen

Total volatile basic nitrogen (TVB-N), a recognized marker of protein degradation and microbial spoilage (Bekhit *et al.*, 2021), demonstrated an upward trend throughout the storage period (Fig 2). TVB-N increased progressively in both dried and smoked fish, with a greater increase under ambient storage than under refrigeration. From an initial level of 6.0 and 8.0 mg N/100 g in dried and smoked fish, respectively, TVB-N increased by day 30 to 31.2 and 30.0 mg N/100 g under ambient storage, compared with 21.3 and 22.3 mg N/100 g under refrigeration. The elevated levels under ambient conditions approached or surpassed the spoilage threshold of 30-35 mg N/100/ g established by the European Commission (E.C. 1995; Bekhit *et al.*, 2021), indicating substantial protein deterioration and loss of freshness. These values were comparable with Ayeloja *et al.* (2020), who reported an increase in TVB-N from 16.50 to 26.62 mg/100 g in smoked *Oreochromis niloticus* during 56 days of storage. Similarly, Pankyamma *et al.* (2025) reported an increase in TVB-N from 19.17 to 49.32 mg/100 g in dried fish during 180 days of ambient storage. Although refrigeration effectively retarded the formation of volatile nitrogenous compounds, it did not fully inhibit spoilage over extended storage. These findings align with earlier reports documenting progressive increases in TVB-N content in smoked and dried fish during storage (Al-Reza *et al.*, 2015; Mosarrat *et al.*, 2016; Jakhar *et al.*, 2025).

Peroxide value

Peroxide value (PV), which reflects the formation of primary oxidation products during lipid degradation (Zhang *et al.*, 2021), showed a progressive increase over the storage period, with markedly higher values in samples stored under ambient conditions (Fig 3). PV increased from 1.6 and 1.9 meq/kg on day 0 in dried and smoked eel, respectively, to 8.5 and 8.5 meq/kg under ambient storage by day 30. Under refrigeration, the corresponding values were lower, reaching 6.3 and 6.9 meq/kg, respectively. The increase indicates progressive lipid peroxidation, which is likely accelerated at higher storage temperatures. Lipid oxidation involves the formation of primary hydroperoxides and their subsequent decomposition into secondary products that may contribute to rancid odours and undesirable flavours (Fitri *et al.*, 2022). PV levels

approaching or surpassing 10-20 meq/kg are generally associated with the onset of rancidity and deterioration in sensory attributes of fish products (Raeisi *et al.*, 2016; Barros *et al.*, 2023). The values observed were comparable with previous reports. Ayeloja *et al.* (2020) reported an increase in PV from 7.74 to 8.18 meq/kg in smoked *Oreochromis niloticus* during 56 days of ambient storage. Salami *et al.* (2024) reported increases from 1.08 to 6.14 meq/kg in oven-dried *Clarias gariepinus* and from 1.92 to 12.94 meq/kg in smoked fish during 42 days of room-temperature storage. More recently, Jakhar *et al.* (2025) reported day-30 PV values of 9.5 and 10.2 meq/kg in dried and smoked *Salmophasia bacaila*, respectively, under ambient storage, compared with 6.3 and 5.33 meq/kg under refrigeration.

Free fatty acids

Free fatty acid (FFA) content, a key indicator of lipid hydrolysis and early-stage rancidity (Daramola *et al.*, 2007; Tenyang *et al.*, 2020), showed a gradual and continuous increase

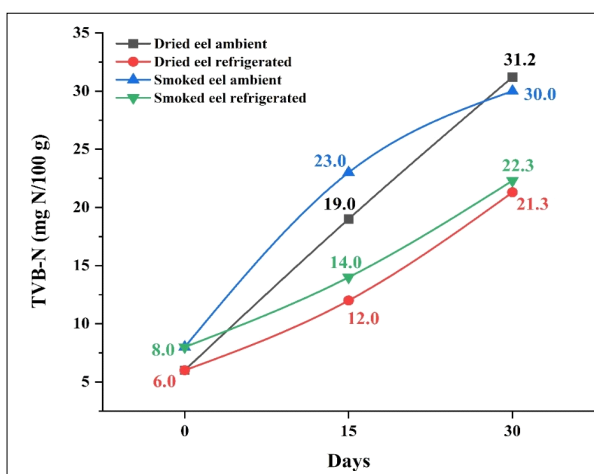


Fig 2: Changes in TVB-N values of smoked and dried eel over time under ambient and refrigerated storage conditions.

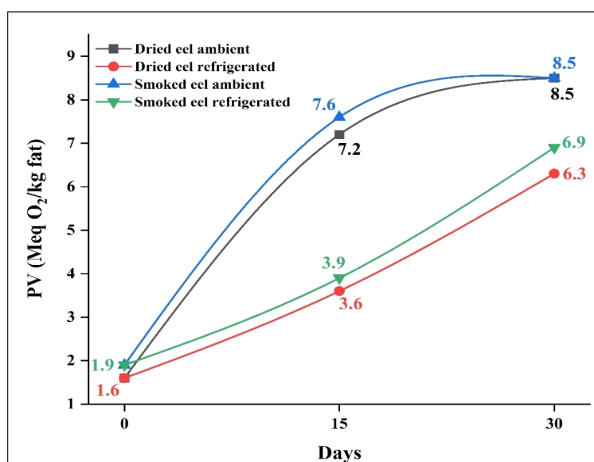


Fig 3: Changes in PV values of smoked and dried eel over time under ambient and refrigerated storage conditions.

during the storage period (Fig 4). FFA increased from 0.2% and 0.4% oleic acid on day 0 in dried and smoked fish, respectively, to 2.1% and 2.3% under ambient storage by day 30. Under refrigeration, the corresponding values increased to 1.2% and 1.5%, respectively. The greater accumulation of FFA under ambient conditions suggests enhanced lipid hydrolysis, potentially associated with greater enzymatic and microbial lipase activity (Ye *et al.*, 2024). Similar increases have been reported in traditionally dried and smoked fish. Jakhar *et al.* (2025) reported FFA increases from 0.45 to 2.85% in smoked *S. bacaila* under ambient storage and from 0.45 to 1.30% under refrigeration, while dried fish increased from 0.25 to 2.61% and 2.30%, respectively. These findings are consistent with previous reports documenting the accumulation of FFAs in smoked and dried fish during storage (Daramola *et al.*, 2007; Ayelaja *et al.*, 2020). Despite evident lipid breakdown in both storage conditions, the reduced FFA formation in refrigerated smoked samples suggests that lower temperatures effectively limit microbial and enzymatic lipolysis (Suárez-Medina *et al.*, 2024). FFA concentrations ranging from 0.5% to 1.5% oleic acid are associated with perceptible rancid odors and flavors, negatively impacting the sensory quality and consumer acceptability of fish products (Daramola *et al.*, 2007).

Microbial changes

The initial total plate count (TPC) was 4.58 and 3.27 log CFU/g in dried and smoked eel, respectively. TPC increased progressively during the 30-day storage period, reaching 5.80 and 5.34 log CFU/g in dried eel under ambient and refrigerated conditions, respectively, while smoked eel reached 4.75 and 4.50 log CFU/g under the corresponding conditions (Fig 5). The initially low microbial loads may be attributed to reduced water activity in both dried and smoked products, which suppresses microbial growth (Fitri *et al.*, 2022). The lower TPC observed in smoked eel than in dried eel may be attributed to the combined effects of thermal treatment and antimicrobial smoke constituents, particularly phenolic compounds, formaldehyde, acetic acid and other organic acids (Adeyeye *et al.*, 2015). Smoke-derived phenolics possess antimicrobial properties and can contribute to microbial inhibition in smoked fish (Adeyeye *et al.*, 2015; Sulfiana *et al.*, 2026). The present TPC values were comparable with recent findings of Sulfiana *et al.* (2026), who reported an increase from 2.84 to 6.68 log CFU/g in traditionally smoked *Rastrelliger kanagurta* during 6 days of ambient storage. In the present study, smoked eel remained below 5 log CFU/g after 30 days under both ambient (4.75 log CFU/g) and refrigerated (4.50 log CFU/g) storage, whereas dried eel exceeded 5 log CFU/g under both conditions. As per microbiological standards for fish and fishery products, TPC levels exceeding 5 log CFU/g are indicative of potential spoilage and decreased consumer acceptability, particularly in dried and smoked products (FSSAI, 2023). Thus, the comparatively lower TPC in smoked eel

suggests reduced microbial proliferation, likely due to the combined preservative effects of dehydration, heat treatment and antimicrobial smoke constituents. The observed TPC values provide an indication of the overall microbial load and its changes during storage; however, TPC alone does not provide information on the presence or absence of specific foodborne pathogens.

Sensory changes

The sensory evaluation of dried and smoked eel was conducted using a 9-point hedonic scale, revealing a decline in overall acceptability from day 0 to day 30 of storage (Fig 6). On day 0, both products received high scores, indicative of their initial freshness and favorable organoleptic attributes. The progressive decline in sensory scores during storage may be associated with lipid oxidation, microbial proliferation, proteolytic changes and the accumulation of volatile compounds responsible for

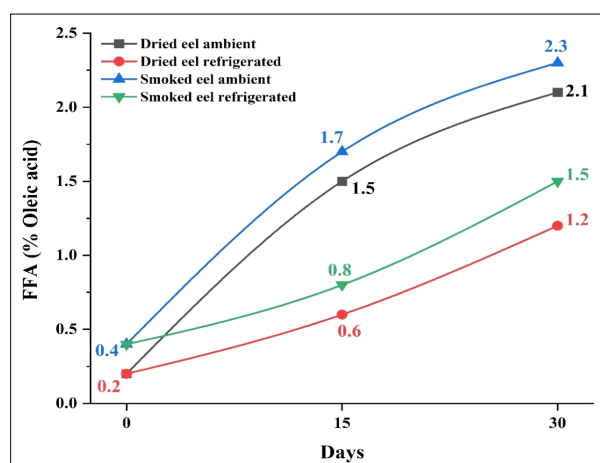


Fig 4: Changes in FFAs values of smoked and dried eel over time under ambient and refrigerated storage conditions.

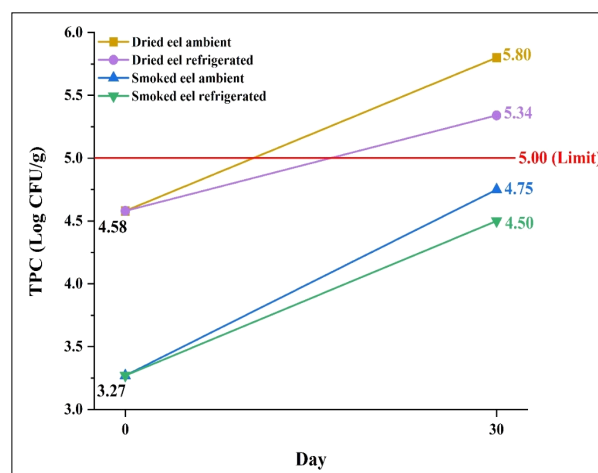


Fig 5: Changes in microbial quality of smoked and dried eel at an ambient and refrigerated temperature on 0th and 30th day.

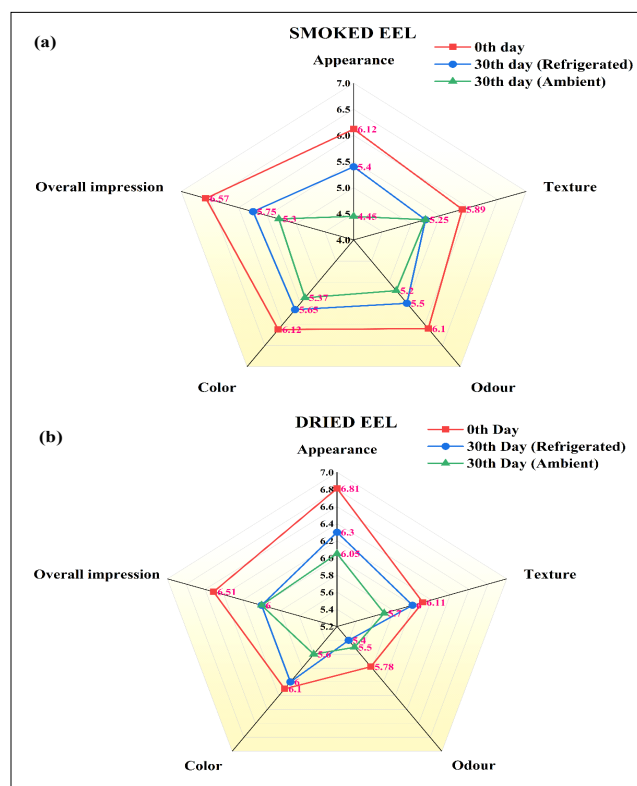


Fig 6: Radar diagram showing sensory attributes of smoked and dried eel stored at ambient and refrigerated temperatures on the 0th and 30th day (n=20).

undesirable odours and flavours (Jakhar *et al.*, 2026). These deteriorative reactions are generally accelerated under ambient conditions, resulting in greater loss of sensory acceptability than under refrigeration (Tavares *et al.*, 2021; Pan *et al.*, 2025). Conversely, refrigerated storage better preserved sensory attributes, which is consistent with the lower microbial growth and slower lipid oxidation observed in the present study. The greater sensory deterioration under ambient storage therefore corresponds with the increases observed in TVB-N, PV, FFA and TPC, supporting their combined contribution to the decline in overall acceptability.

Study limitations

The present study has several limitations that should be considered when interpreting the biochemical and microbial findings. First, biochemical and microbial analyses were conducted using a single biological sample for each treatment, with replicate measurements representing analytical rather than independent biological replicates. Therefore, statistical inference and estimates of biological variability could not be appropriately established for these parameters and the observed changes should be interpreted descriptively. Second, ambient storage was conducted under a relatively broad temperature range of 20–40 °C and the temperature was not continuously monitored throughout the storage period. Consequently,

temporal fluctuations in ambient temperature may have contributed to the observed changes and limit the ability to attribute differences solely to a defined storage temperature. Third, water activity (a_w) was not measured in the present study. Thus, although changes in moisture content were observed, the relationship between water availability and microbial or biochemical changes could not be directly assessed. Future studies should incorporate multiple independent biological replicates, continuous monitoring of storage temperature and relative humidity and direct measurement of a_w to provide more robust and mechanistic assessments of the storage stability of traditionally processed fish products.

CONCLUSION

This study highlights the important influence of storage conditions on the overall quality of traditionally smoked and dried zig-zag eel (*M. armatus*) marketed in Kawardha, Chhattisgarh. The findings indicate that ambient storage accelerates physicochemical deterioration, microbial proliferation and sensory decline, resulting in greater deterioration of product quality over time. Refrigerated storage slowed physicochemical degradation, microbial growth and sensory deterioration, thereby helping to maintain the overall quality of the products during the investigated 30-day storage period. For rural fish processors and vendors, the findings emphasize the importance of hygienic processing and handling, adequate drying and smoking, appropriate packaging and refrigerated storage where feasible to minimize microbial and physicochemical deterioration and maintain product quality. The findings also highlight the need for improved post-harvest handling and cold storage infrastructure to help maintain the quality and acceptability of traditionally processed fish products. The present findings provide practical information on storage-related changes in the quality of traditionally smoked and dried *M. armatus*.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Verbal informed consent was obtained from all sensory panelists prior to their participation in the sensory evaluation.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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