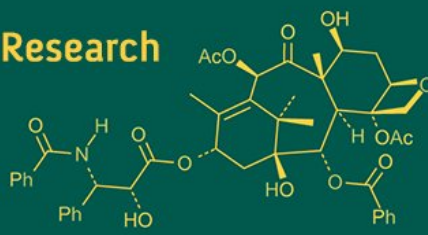


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Design and development of a portable aluminium insulated box for transportation of fresh fish

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Abstract

The aim of the research was to design and development of aluminium insulated box for transportation of fresh fish and evaluating its thermal performance, biochemical and microbial parameters using crushed ice. The unit capacity of 3.429 L and dimension was 22cm × 22cm × 22cm (L×B×H). This insulated box made out of aluminium sheet. The polyurethane foam used as an insulating material with a thickness of 3 cm. The insulating capacity of aluminium insulated box was tested in the processing unit for a period of 7 days by loading crushed ice with Indian mackerel (*Rastrelliger Kanagurta*). Density (ρ_r) and porosity (ϵ) of polyurethane foam (PUF) was determined as 1.0289 g/cm³ and 30.03% respectively. The performance evaluation of insulated box under ambient condition (32-33 °C) assessed heat transfer rate, melting rate of ice and no-load test of insulated box. The heat transfer rate was observed to be 6.4009 W with an internal temperature of 3.25 ± 0.26° C, which is indicating the melting rate of ice was 21.25 ± 0.25% on day 1 and 23.91 ± 0.38% on day 7, the no-load ice retention was observed to be 4.14 ± 0.03 days. The influence of ice storage on mackerel was evaluated during the 7 days storage study. The ice and fishes were arranged in the insulated box with a ratio of 1:1 (ice: fish). Quality parameters such as Total Volatile Base Nitrogen (TVB-N), Peroxide value (PV) and Total Plate count increased significantly. The sensory scores for overall acceptability were found to be decreased significantly. This study showed that, the aluminium insulated box is effective in extending the keeping quality of fish up to 7 days in iced condition and can be recommended for marketing of fresh fish over existing counterparts in the market.

Keywords: Heat transfer rate, melting rate of ice, no-load test, aluminium insulated box, quality assessment, sensory evaluation

Introduction

In fish industry, high perishability rate of the raw material is recorded immediately after the harvesting of fishes. The waste of fish due to improper handling leads to income loss for fisherman, fish traders and contribute to food insecurity. In order to reduce these losses, using chilling method to extend the fish storage time on both onboard and at the shore (Atanda *et al.* 2022) [4]. The traditional containers such as bamboo basket and wooden boxes are used to transport the fresh fish from the landing centers to distant market (Rao *et al.* 1981) [16]. But those traditional materials are having some demerits such as less mechanical strength, less shelf life, difficult to keep clean and sanitized. The plastic insulated boxes can lead for accumulation of micro plastic on fish body (Shawyer and Pizzali, FAO. 2003) [19]. Ice is used to transport the harvested fish from the landing centers to market or processing units because ice is used as a chilling substance to keep the fish at low temperature to reduce the fish spoilage (Margeirsson *et al.* 2017) [11]. The insulated box widely used from the small-scale application to large scale applications such as events, and cold chain logistics. Different type of insulated boxes used to keep perishable foods or drink at low temperature. The conventional cool box is made from aluminium, can maintain the low temperature for 24 hours, this can be achieved by providing better insulation (Khairulmaini *et al.* 2020) [9]. The insulating material should be durable and waterproof. A good insulator will maintain the internal temperature of the box for a long time. Polyurethane foam is the cost-effective insulating material; it has low thermal conductivity and good mechanical properties (Atanda *et al.* 2022) [4].

Materials and methods

Experimental design

The aluminium ice box was designed with locally available aluminium sheet and polyurethane foam. The inner and outer box was made by using an aluminium sheet with a thickness of 0.05cm. The dimension for inner box was 22cm(H)×22cm(W)×22cm(L) and for outer box was 25cm(H)×25cm(W)×25cm(L). The inner box was placed inside the outer box, and the insulating material polyurethane foam was fitted in between the boxes. The handle was fitted on the top of the box for handling and transportation.

Sample Preparation

Fresh Indian mackerel (*Rastrelliger Kanagurta*) fish of average total length and weight were 16.17 ± 0.25 cm and 70.14 ± 2.07 g, respectively was procured from Mirkarwada Landing Center, Ratnagiri. The fish was segregated, washed in fresh water and transferred to aluminium insulated box. Crushed ice and fish were used in the ratio of 1:1 (ice: fish). The aluminium insulated box was kept in the laboratory for 7 days of storage study. The ice was replenished once in 24 h after draining the melted water. The sample was drawn on each day of storage study for analysis. The sample was randomly dissected by hand to get their muscle and was subjected for biochemical, microbiological and sensory studies.

Performance test

Temperature

The temperature was measured by using glass thermometer twice in a day. The thermometer was inserted inside the box and left for 2 minutes until a stable reading is obtained (Khairulmaini *et al.* 2020)^[9].

Heat transfer rate

Heat transfer rate per day was determined by measuring the surrounding and inside box temperature. Following formulae used to calculate the heat transfer rate of box (Shah and Dake. 2016)^[18].

$$q = \frac{Ax\Delta T}{L/k}$$

Where,

q = heat transfer rate in W/m/k

A = height × length

ΔT = temperature difference = surrounding temperature - inside temperature

L = thickness of the insulating material

K = thermal conductivity of material

Specific ice melting rate

The ice melting rate was estimated by the method described by (Nowsad *et al.* 2013)^[14]. The crushed ice was completely filled inside the boxes. Before filling, the weight of the ice was taken. Melted water has been drained out at 24 h interval. The specific ice melting rate was calculated by the following formula:

$$k = \frac{\text{Amount of melted ice (l)}}{\text{Total amount of ice used (g)}} \times 100$$

No-load test

The box was filled with 2 kg of crushed ice and placed the box in processing unit. How much hours required to complete melting of ice in which amount of ice was present

after 24 hours of sampling was analyzed (Atanda *et al.* 2022)^[4].

Density

The Polyurethane foam (PUF) was cut into rectangular block. The weight of the block in air and water was Measured (Khairulmaini *et al.* 2020)^[9]. The density of PUF was calculated by the following formula:

$$\rho_r = \frac{w_a}{w_a - w_w} \times \rho_w$$

Where,

ρ_r = density of foam in g/ cm³

w_a = weight of the foam in air in g

w_w = weight of the foam in water in g

ρ_w = density of water in g/ cm³

Porosity

Porosity of the polyurethane foam (PUF) calculated by using bulk density and true density of PUF (Khairulmaini *et al.* 2020)^[9]. The following formula used to calculate the porosity of PUF.

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_r}\right) \times 100$$

Where,

ε = porosity of foam in %

ρ_b = bulk density of the foam in air in g/ cm³

ρ_r = density of foam in g/ cm³

Quality evaluation of iced Indian mackerel

Sensory evaluation

Sensory evaluation of the iced fish was carried out by a panel of 10 panellists by assessing attributes such as appearances, colour, odour and over all acceptability using “1 to 9” point hedonic scale. High score indicated the good quality. The individual scores from panellists were pooled and the average scores for each attribute were calculated (Chudasama *et al.* 2018)^[5].

Biochemical analysis

Peroxide value (PV)

The peroxide value was expressed as milli equivalent of O₂ / kg of fat. About 10 g of sample was macerated with 15 g of anhydrous sodium sulphate in a motor and pestle for the purpose of dehydration. After maceration, sample was extracted by using 30 ml of chloroform by standard method as per the method of AOAC (2005)^[3]. Peroxide value as milli equivalent of O₂ / Kg of fat was determined using formula:

$$\text{PV (milliequivalent of O}_2 \text{ / kg of lipid)} = \frac{\text{TV} \times \text{N} \times 1000}{w}$$

Where,

TV = Volume in ml of N/100 sodium thiosulphate used for titration

N = Normality of sodium thiosulphate

W = Weight of fat

Total Volatile Base Nitrogen (TVB-N)

A 10 g portion of the iced fish was homogenized with 20 ml of 20% trichloroacetic acid (TCA). The mixture was then filtered through Whatman No. 1 filter paper into a 50 ml volumetric flask. The extraction process was repeated and the filtrate was diluted to 50 ml with TCA. For analysis, 1

ml of N/70 sulfuric acid (H_2SO_4) and a drop of Tashiro's indicators were placed into the chamber of a Conway micro-diffusion unit. In the outer chamber, 1 ml of the TCA extract was added and the unit was covered with a greased glass lid, leaving a small gap to introduce potassium carbonated (K_2CO_3). Then 1 ml of K_2CO_3 was gently added to the outer chamber and the unit was sealed completely. The setup was left at room temperature overnight. After incubation, the contents of the inner chamber were titrated against N/70 sodium hydroxide (NaOH) using a microburette until a color change was observed. A blank titration was carried out simultaneously using 1 ml of 2% TCA solution (Chudasama *et al.* 2018) [5].

$$\text{TVB-N (mg/100gm)} = \frac{V \times 0.2 \times 50 \times 100}{w}$$

Where,

V = Difference in the titre values of blank and sample

0.2 = Nitrogen conversion factor

50 = Dilution factor

W = Weight of fish in g

Total Plate Count (TPC)

Preparation of homogenate

A 10 g of the sample was aseptically weighted and transferred into 90 ml of sterile physiological saline solution. The sample was then ground and homogenized using a sterile motor and pestle as per the standard procedure by AOAC (2005) [3].

Sterilization

Glasswares used for microbiological quality was sterilized as per the standard method of AOAC (2005) [3].

Estimation of total plate count (TPC): Serial dilution of the homogenate was prepared using physiological saline and 1 ml from each dilution was inoculated into sterile petri

dishes containing Plate Count Agar (PCA) using the pour plate technique. The plates were incubated at 37°C for 48 hours. After incubation, colonies that developed on the agar surface were counted. Only the plates yielding colony counts within the acceptable range of 30 to 300 were considered for analysis following the guidelines outlined by USFDA (2022).

Total plate count (cfu/g) = Average counts of colonies $\times$ Dilution factor

Statistical analysis

All collected data were statistically analyzed using statistical tool available in SPSS version 27 (Amitha *et al.* 2019) [2]. The analysis was carried out in triplicate ($n=3$). Analysis of variance (One way - ANOVA) was performed to compare the storage days of aluminium insulated box during storage study. Significance of differences was defined at $p < 0.05$.

Results

Performance test: The performance test of aluminium insulated box such as, measurement of temperature, heat transfer rate, melting rate of ice, and No-load are shown in Table 1. The average internal temperature was maintained at $3.25 \pm 0.26^\circ\text{C}$. The heat transfer rate was recorded as $6.40 \text{ W/m}\cdot\text{K}$, which reflects the thermal conductivity of the insulating material. The melting rate of ice inside the box was observed to be $24.28 \pm 0.30\%$. The No-load test showed a time to melt total 2.0 Kg of ice was 4.14 ± 0.03 days.

The result of Polyurethane foam parameters such as density and porosity are shown in Table 2. PUF having density of 1.0289 g/cm^3 and porosity of 30.03%. For insulation applications, materials with low porosity are recommended, as an increase in porosity reduces the material's thermal resistance, thereby facilitating higher heat transfer rates.

Table 1: Result for performance test of aluminum insulated box

Sr.No.	Performance test	Observed values
1	Temperature ($^\circ\text{C}$)	$3.25 \pm 0.26^\circ\text{C}$
2	Heat transfer rate ($\text{W/m}\cdot\text{K}$)	$6.40 \text{ W/m}\cdot\text{K}$
3	Melting rate of ice (%)	$24.28 \pm 0.30\%$
4	No-load test (days)	4.14 ± 0.03

Mean $\pm$ SD for each parameters represents the percentage composition of three determinations ($n=3$)

Table 2: Result for polyurethane foam (PUF) parameters

Mass, m (g)	Volume, V (g)	Density ρ_r (g/cm^3)	Bulk density ρ_b (g/cm^3)	Porosity ϵ (%)
25.38	35.26	1.0289	0.71	30.03

Mean $\pm$ SD for each parameters represents the percentage composition of three determinations ($n=3$)

Quality evaluation of iced Indian mackerel: The quality parameters of the iced Indian mackerel such as sensory

evaluation, biochemical analysis (PV, TVB-N) and microbial quality characteristics are shown in Table 3 and 4.

Table 3: Sensory evaluations of indian mackerel during chilled storage

Storage Days	Sensory quality attributes			
	Appearance	color	odour	Overall acceptability
0	9.46 ± 0.05^a	9.39 ± 0.07^a	9.45 ± 0.05^a	9.46 ± 0.05^a
1	9.05 ± 0.05^b	9.11 ± 0.08^b	9.10 ± 0.08^a	9.13 ± 0.08^a
2	8.55 ± 0.05^c	8.56 ± 0.05^c	8.69 ± 0.08^{ab}	8.59 ± 0.07^a
3	8.10 ± 0.08^d	8.05 ± 0.05^d	8.13 ± 0.09^b	8.13 ± 0.08^b
4	7.19 ± 0.11^e	7.10 ± 0.09^e	7.14 ± 0.09^c	7.10 ± 0.09^c
5	6.18 ± 0.10^f	6.27 ± 0.06^f	6.13 ± 0.10^d	6.12 ± 0.07^d
6	5.22 ± 0.09^g	5.25 ± 0.07^g	5.14 ± 0.09^e	5.13 ± 0.08^e
7	4.16 ± 0.08^h	4.21 ± 0.05^h	4.16 ± 0.12^e	4.11 ± 0.08^e

Values are presented as mean $\pm$ standard deviation ($n=10$). Statistical analysis was performed using one-way ANOVA followed by Turkey's HSD post hoc test to determine significant difference among the storage days. Means with different superscript letters within the same row indicate significant difference ($p < 0.05$), while means sharing common superscripts are not significantly different. Sensory evaluation was conducted using a 9-point hedonic scale (9=like extremely; 1 = dislike extremely)

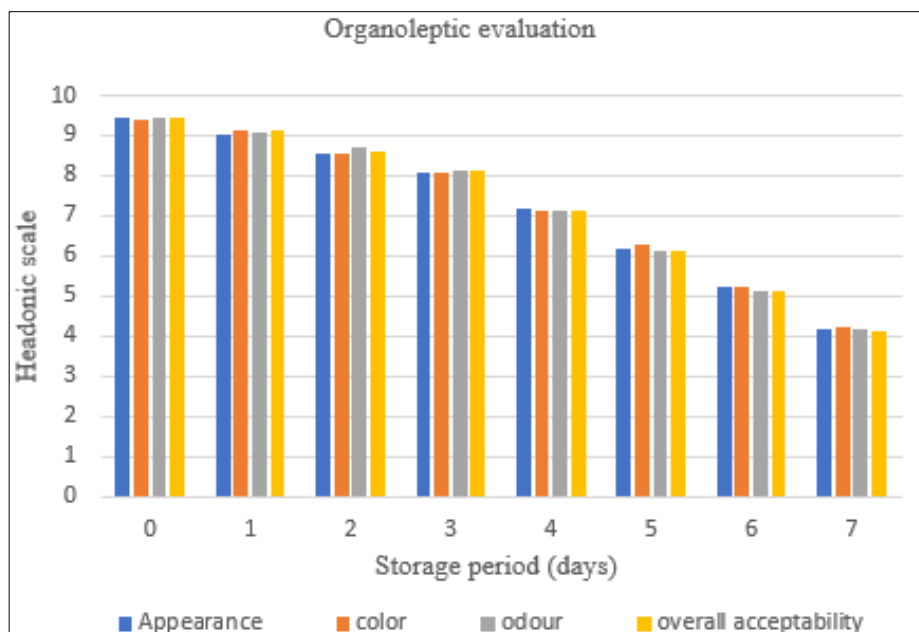


Fig 1: Mean result of sensory characteristics for chilled storage of Indian mackerel

Table 4: Peroxide value (PV), TVB-n, TPC of Indian mackerel during chilled storage

Storage days	Peroxide value (O ₂ / Kg of fat)	TVB-N (mg/100gm)	Total Plate count (cfu/g)
0	2.33 ± 0.27 ^a	6.36 ± 0.11 ^a	(2.77 ± 0.25) × 10 ^{2a}
1	3.71 ± 0.36 ^b	6.83 ± 0.05 ^b	(1.20 ± 0.10) × 10 ^{3b}
2	4.33 ± 0.20 ^c	8.83 ± 0.15 ^c	(1.07 ± 0.03) × 10 ^{4c}
3	5.77 ± 0.30 ^d	11.13 ± 0.32 ^d	(2.05 ± 0.06) × 10 ^{4d}
4	7.17 ± 0.36 ^e	13.23 ± 0.15 ^e	(3.53 ± 0.23) × 10 ^{4e}
5	8.44 ± 0.56 ^f	15.90 ± 0.10 ^f	(5.37 ± 0.40) × 10 ^{4f}
6	9.77 ± 0.30 ^g	20.80 ± 0.20 ^g	(7.27 ± 0.30) × 10 ^{4g}
7	10.70 ± 0.31 ^g	23.90 ± 0.36 ^h	(9.43 ± 0.35) × 10 ^{4h}

Values are mean ± standard deviations. Different superscripts for the same column indicated significant difference.

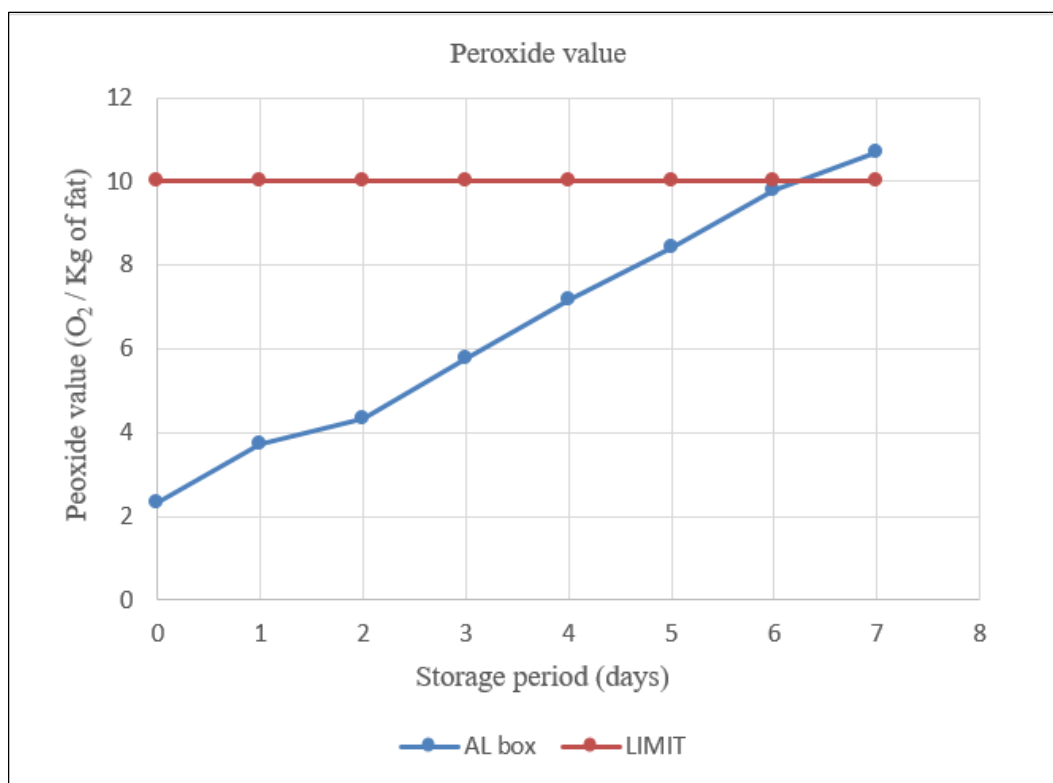


Fig 2: Mean result of peroxide value for iced storage of Indian mackerel

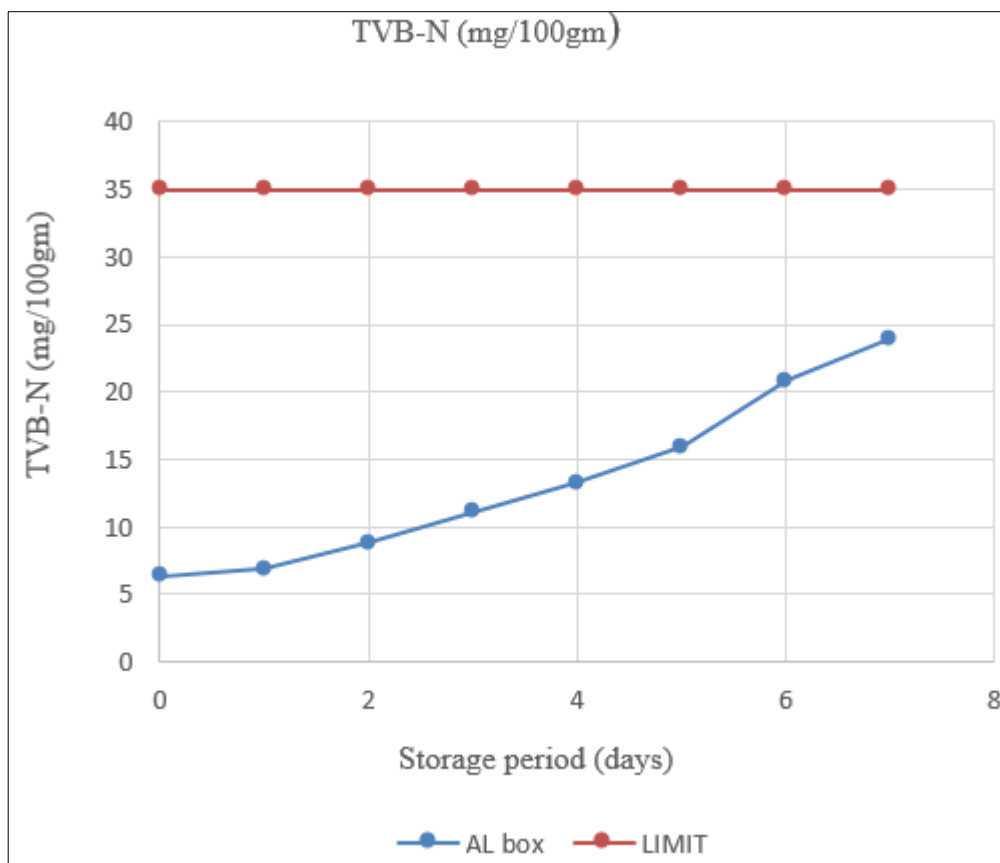


Fig 3: Mean result of TVB-N for iced storage of Indian mackerel

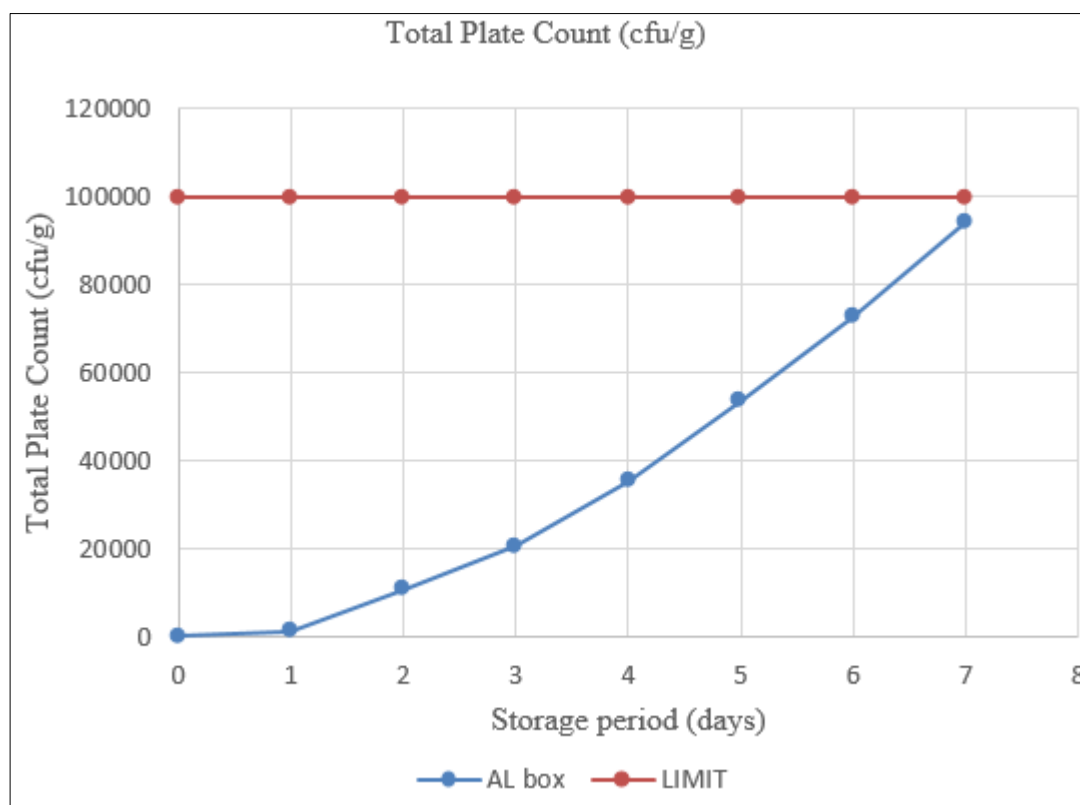


Fig 4: Mean result of TPC for iced storage of Indian mackerel

Discussion

Performance test

The research demonstrated that the newly developed aluminium insulated box, incorporating polyurethane foam (PUF) as the insulating material. The box maintained a

stable internal temperature of 3.25 ± 0.26 °C, with a low heat transfer rate of 6.40 W/m·K and an ice retention capacity of 4.14 ± 0.03 days during the no-load test throughout the 7-day storage period. This superior performance is primarily attributed to the synergistic effect

of the low thermal conductivity of polyurethane foam and the radiant barrier properties of the aluminium surface. Polyurethane foam is recognized for its exceptionally low thermal conductivity, typically ranging from 0.020 to 0.023 W/m·K, which is significantly lower than other conventional insulating materials (Manik *et al.*, 2024; Shah and Dake, 2016) ^[10, 18]. The incorporation of aluminium sheets as the inner and outer casing provides an additional thermal barrier. The aluminium surface acts as a radiant barrier, reflecting thermal radiation and reducing heat ingress. Similarly demonstrated that adding an aluminium foil radiant barrier to an insulated package improved its thermal performance by 46%, confirming the effectiveness of combining conductive insulation with a reflective surface (Wang *et al.*, 2020) ^[22]. Similarly reported that an aluminium foil composite prototype achieved superior thermal resistance compared to conventional EPS foam boxes, further validating the design approach employed in the present study (Mwenya *et al.*, 2024) ^[12]. The ice retention performance observed in the no-load test (4.14 ± 0.03 days) is consistent with findings by (Atanda *et al.*, 2022) ^[4], who reported that PUF insulated box-maintained ice for approximately 3 days at ambient temperature. The slightly longer ice retention observed in the present study may be attributed to the reflective properties of the aluminium casing, which reduces radiative heat gain. The density of the polyurethane foam used in the present study is 1.0289 g/cm³ and its porosity is 30.03%. Similarly reported that lower porosity in PUF foam contributes to a reduced heat transfer rate and enhanced thermal insulation performance (Khairulmaini *et al.*, 2020) ^[9].

Quality evaluation of iced Indian mackerel

Sensory evaluation

The sensory quality of Indian mackerel stored in the aluminium insulated box was evaluated using a nine-point hedonic scale, where scores of 5 or above indicate acceptable quality for human consumption. The fish maintained acceptable sensory scores for all attributes (appearance, colour, odour, and overall acceptability) up to Day 6, with overall acceptability declining gradually from 9.46 ± 0.05 on Day 0 to 5.13 ± 0.08 on Day 6, and falling below the acceptability limit only on Day 7. This corresponds to a sensory shelf life of 7 days for fish stored under the experimental conditions. Similarly, the study of quality changes in physiochemical and sensory characteristics of iced fish reported that the sensory quality of Indian mackerel using the same nine-point hedonic scale and that fish stored under iced conditions maintained acceptable quality for up to 5 days (Chudasama *et al.*, 2018) ^[5]. The extended shelf life observed in the present study (7 days) demonstrates the superior insulation provided by the aluminium PUF insulated box. The nine-point hedonic scale is a well-validated sensory evaluation tool in fish processing research, where scores of 5 or above indicate acceptable quality for human consumption (Nowsad, 2007) ^[13].

Peroxide Value (PV)

The peroxide value, a key indicator of primary lipid oxidation, was monitored throughout the 7-day storage period. The aluminium insulated box effectively retarded the accumulation of primary oxidation products, with the PV increasing from an initial value of 2.33 ± 0.27 meq/kg to 10.70 ± 0.31 meq/kg by Day 7. This value remains well

below the rancidity threshold of 20 - 40 meq/kg established by SEAFDEC standards, indicating that the fish maintained acceptable lipid quality throughout the storage period.

Similarly, the study reported initial PV values of approximately 2.2-2.5 meq/kg for Indian mackerel under conventional icing, which aligns precisely with the initial PV observed in the present study of 2.33 ± 0.27 meq/kg (Viji *et al.*, 2016) ^[21]. This slow progression of lipid oxidation is directly attributable to the stable low-temperature environment maintained by the aluminium insulated box. Similar result was found in lower storage temperature directly controls spoilage in Indian mackerel, with fish at 4 °C showing significantly slower quality deterioration compared to those at higher temperatures (Humaid and Jamal, 2014) ^[7].

Total Volatile Base- Nitrogen

TVB-N is a widely used biochemical indicator of protein degradation in fish, reflecting the accumulation of volatile nitrogenous compounds produced by microbial activity and endogenous enzymes. In the present study, the aluminium insulated box was highly effective at retarding protein degradation, with the TVB-N value increasing from 6.36 ± 0.11 mg/100g on Day 0 to only 23.90 ± 0.36 mg/100g by Day 7, remaining well below the European Union regulatory limit of 35 mg/100g for fishery products.

The TVB-N value observed on Day 7 in the present research of 23.90 mg/100g confirms that the fish remained well within acceptable limits even at the end of the storage period. Similarly, that chilled mackerel reached a TVB-N content of 37.34-37.57 mg N/100g precisely on the day the fish were rejected by a sensory panel (Day 7), thereby establishing 35 mg/100g as the spoilage limit for this species (Panguila *et al.*, 2018) ^[15]. The iced marine fish species and reported that TVB-N values increased progressively with storage time, with fish reaching the rejection limit by Day 3 of storage (Al-Najada, 2019) ^[1]. The prolonged shelf life observed in the present study the fish remained well below the rejection limit on Day 7, demonstrates the superior temperature control achieved by the aluminium insulated box.

Total Plate Count (TPC)

Total Plate Count is the most widely used microbiological index for assessing the overall spoilage status of fresh fish. According to the (ICMSF, 1986), plate counts below 5.5×10^5 CFU/g are considered good quality, while counts at or above 10^7 CFU/g are considered unacceptable. In the present study, the initial TPC of Indian mackerel was recorded as $(2.77 \pm 0.25) \times 10^2$ CFU/g on Day 0, similar result found in the initial TPC values of 10^2 - 10^3 CFU/g for freshly caught Indian mackerel procured directly from landing centres (Gopalakrishnan *et al.*, 2016) ^[1]. In the aluminium insulated box, the TPC increased progressively from $(1.20 \pm 0.10) \times 10^3$ CFU/g on Day 1 to $(9.43 \pm 0.35) \times 10^4$ CFU/g on Day 7, remaining below the ICMSF rejection limit throughout the entire 7-day storage period. This slow increase in bacterial population is a direct consequence of the stable, low-temperature environment maintained by the aluminium insulated box, which effectively suppressed the growth of spoilage microorganisms.

Conclusion: In the present research after analysis of results and its comparison with the existing published literature, the

aluminium insulated box with polyurethane foam insulation demonstrated significant potential to reduce post-harvest losses in tropical fisheries by extending fish shelf life by 2-3 times compared to conventional plastic boxes. The aluminium insulated box effectively retarded heat transfer, lipid oxidation, and microbial growth, extending the sensory shelf life 7 days. The study recommends that the aluminium insulated box should be promoted among small-scale fishers and fish traders as an affordable and effective cold chain solution. The results of this study provide a base for the future studies focusing on optimization of PUF-aluminium composite insulation, evaluation of long-term structural durability under repeated use, and field-scale validation of the aluminium insulated box in real-world fisheries supply chains, particularly under varying climatic conditions and handling practices.

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