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# Development and quality enhancement of dried kiddi shrimp, *Parapenaeopsis stylifera* (H. Milne Edwards, 1837) using hurdle technology

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**Abstract**
Shrimp is a highly valued seafood globally, appreciated for its rich nutritional value. Due to the highly perishable nature and enzymatic activity, effective preservation methods are required to preserve the quality and shelf life of shrimp. The present study aimed to extend and improve the quality of dried shrimp by using hurdle technology, such as dipping in citric acid, followed by blanching (5% NaCl) method, and drying using conventional and non-conventional methods, such as solar tunnel dryer and electric cabinet dryer, respectively. The dried shrimp treated with 0.6% citric acid were selected among the 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% for a 90-day storage study, packed in HDPE and LDPE bags at ambient temperature. The parameters such as TMA (6.33±0.02 mg/100 g), TVB-N (16.33±0.03mg/100 g), FFA (0.74±0.01% of oleic acid), pH (6.40±0.01), PV (0.95±0.02 meq$O_2$/kg of fat), TPC (2.48±0.01) and moisture content (14.79±0.03%) was increased, whereas protein (70.53±0.01%), fat (3.22±0.02%), ash (11.37±0.02%) and salt content (3.13±0.02%) was decreased with significant difference ($p$<0.05) throughout the storage period for solar tunnel dryer dried and packed in HDPE packed sample shows higher acceptability by panellist even after end of 90 days compared to other samples.

**Keywords:** Dried kiddi shrimp, solar tunnel dryer, electric cabinet dryer, citric acid, packaging

## Introduction
Many coastal and interior tribes have long included shrimp as a mainstay in their traditional diets because of its flavor and nutritional value. Shrimp are low in calories and high in valuable proteins, minerals, trace elements, essential amino acids, including long-chain n-3 fatty acids, and fat-soluble vitamins (Chakraborty, 2025) [12].

One of the earliest, simplest, least expensive, and most efficient ways to preserve food is by drying it, especially in warm-weathered poor nations (FAO, 2001) [24]. It stops most bacteria from forming by reducing the moisture level of the food to less than 15% to 20%. Shrimp has a high protein and moisture content, which causes it to degrade and spoil quickly. Maintaining quick preservation through a continuous cold chain is ideal, but it can be difficult in locations with irregular or nonexistent energy, according to Akonor *et al.* (2016) [2]. In some situations, drying shrimp is a practical and economical method of extending their shelf life without diminishing their nutritional value.

In hurdle technology, different preservation parameters (such as pH, aw, temperature, antimicrobial ingredients, packaging, etc.) are used in combination with two or more hurdles to achieve maximum lethality against microorganisms while minimizing harm to the food's organoleptic qualities (Singh and Shalini, 2016) [36]. The manufacture of dried shrimp primarily consists of two stages: boiling to deactivate microorganisms and drying (Tapaneyasin *et al.* 2005) [38]. Pretreatment techniques have been shown to reduce drying time significantly, enhance product yield and sensory attributes, improve the overall quality of the dried product, inhibit enzymatic browning, aid in the retention of volatile compounds, and extend the product's shelf life (Omodara and Olaniyan 2012; Abano *et al.* 2013; Qiu *et al.* 2019) [29, 1, 32].

Synthetic or natural food preservatives are used to stop the growth of microbes and the oxida tion of lipids in food (Bhor *et al.*, 2024) [10].

Citric acid, an organic acid, an inexpensive, non-toxic organic acid, is widely used in the food industry for its antioxidant, antibacterial, and cryoprotective properties for food preservation (Nakai and Siebert 2003; Theron and Lues 2007) [27, 39].

Notably, food technologists claim that qualities like color (especially redness), shape (size), and rehydration capacity—all of which affect the dried product's quality—are the main factors influencing dried shrimp prices (Karathenos *et al.* 1996; Quiroz and Nebra 2001; Tapaneyasin *et al.* 2005) [25, 33, 38]. In addition to guaranteeing containment, convenience, communication, and quality preservation, effective packaging is essential for preventing microbial, biochemical, and physical degradation (Restuccia *et al.* 2010) [35].

**Material and Method:**

Kiddi shrimp were procured from the local fish market of Ratnagiri and transported in an insulated box filled with crushed ice in a 1:1 ratio. They were then taken to the fish processing hall at the College of Fisheries, Ratnagiri, for further processing. Whole kiddi shrimp were washed with chlorinated water. After washing, the shrimp were divided into six lots based on the concentration of citric acid. Each lot was soaked in a different concentration of citric acid, viz. 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1% for 20 minutes. The shrimp were then blanched in 5% brine at a shrimp-to-brine ratio of 1:1 for approximately 8-10 minutes. The blanched shrimp was dried in a solar tunnel dryer at 48-50°C for 14 hours, depending upon environmental conditions. After drying, peeled samples were subjected to quality assessment, including sensory, proximate, biochemical, and microbial analyses. The appropriate treatment was selected and packed in HDPE bags for a 90-day storage study at ambient temperature.

**Organoleptic evaluation**

Organoleptic evaluation was based on the various organoleptic characters. A panel of 10 judges performs the organoleptic analysis of dried kiddi shrimp samples during the ambient storage. The samples were evaluated by a 1 to 9 point hedonic scale (Poste *et al.* 1991) [30].

**Proximate analysis**

The proximate composition of dried shrimp, including moisture, crude protein, crude fat, and ash content, was determined according to the standard methods prescribed by AOAC (2005) [4].

**Biochemical analysis**

The chemicals used in the study were of analytical grade. The trimethylamine (TMA) was expressed as mg/100 g and determined by Beatty and Gibbons (1936) [8], total volatile-basic nitrogen (TVB-N) was denoted with mg/100 g and described by Conway (1947) [17], The pH measured by pH meter, peroxide value (PV) was denoted by meq $O_2$/kg of fat and calculated by AOAC (2005) [4], free fatty acid (FFA), salt content was calculated by Mohr's method, were recorded to evaluate the biochemical quality of dried kiddi shrimp treated with various% of citric acid.

**Microbiological evaluation**

Microbiological analysis was carried out for the enumeration of total plate count (TPC) determined in Tryptone Glucose Beef Extract (TGBE) Agar by the spread plate method (USFDA, 2022) [43].

**Statistical analysis**

The statistical analysis for the results of quality analysis of dried kiddi samples was determined using appropriate statistical methods (Snedecor and Cochran, 1967) [37]. A significant difference between the treatments was determined using the one-way ANOVA and Repetitive SPSS.

**Results and Discussion**

**1. The selection of a suitable concentration of citric acid for the storage study**

The dried kiddi shrimp was evaluated for sensory, proximate, biochemical, and microbial count. The kiddi shrimp treated with 1.0% citric acid dried in an electric cabinet dryer and solar tunnel dryer had low moisture content as well as high protein, fat, and ash content. The biochemical content and microbial content are also low in the 1.0% citric acid sample dried by both methods. Panelist highly preferred the sample treated with 0.6% citric acid based on sensory evaluation for storage study and packaging.

**2. Storage study of hurdle-processed dried shrimp**

The sample treated with 0.6% citric acid was packed in an HDPE bag at an ambient temperature, and assessment of organoleptic, proximate, biochemical, and microbial analysis was carried out every 15 days.

**Changes in organoleptic score evaluation of hurdle-processed kiddi shrimp during storage study**

In the present study, treated dried shrimp had an attractive orange colour and firm texture, which was preferred by panellists due to its excellent and highly acceptable organoleptic characteristics. The overall acceptability of the sample dried in the solar tunnel dryer of LDPE bags was decreased from 7.5 to 5 and from 8.9 to 6.8 from the $0^{th}$ to $90^{th}$ day for $T_0S_{LD}$ and $T_1S_{LD}$, respectively. The overall acceptability of the sample packaged in HDPE bags decreased from 7.5 to 5.4 and from 8.9 to 7.1 from $0^{th}$ to $90^{th}$ day for $T_0S_{HD}$ and $T_1S_{HD}$, respectively. At the end of the storage study, the quality of the control dried sample was likely to deteriorate in colour, texture, odour, and overall acceptability compared to the treated dried shrimp. All 4 samples are under the acceptable limit for all parameters, even after the end of the storage period. The organoleptic score decreased due to the colour loss due to astaxanthin destruction by temperature and light exposure, and oxidation of fat content. Similarly, the texture change may be due to absorption of moisture from the surroundings during the storage period, as well as microbial and enzymatic destruction during the storage period. The organoleptic changes are found mostly in the dried shrimp sample packed in an LDPE bag due to its high permeability to moisture, oxygen absorption, and light absorption.

**Changes in proximate composition of hurdle-processed kiddi shrimp during storage study**

The fresh kiddi shrimp (*Parapenaeopsis stylifera*) had 73.03±0.8%, 18.24±0.6%, 6.51±0.3% and 1.20±0.1% of moisture, protein, fat, and ash, respectively.

The moisture content of the untreated dried sample was slightly high moisture content than citric acid-treated sample. At the beginning of the storage study, the moisture content in the untreated sample ($T_0S_{LD}$, $T_0S_{HD}$) and the 0.6% citric acid-treated sample ($T_1S_{LD}$, $T_1S_{HD}$) was 13.22% and 12.03% respectively. On the 90$^{th}$ day, the moisture content was increased to 19.93, 15.99, 19.23, and 14.79% for $T_0S_{LD}$, $T_1S_{LD}$, $T_0S_{HD,}$ and $T_1S_{HD,}$ respectively. A similar trend of an increase in moisture content was observed by Rabie *et al.* (2016) [34] for dried pink shrimp treated with iodine bisulfate (0.5%) and sodium tripolyphosphate (0.5%), dried using sun drying, and packed in polyethylene bags. According to Chowdhury *et al.* (2020) [14] on the salted dried barb fish packed in three packaging materials had 1.43% on day 0. At the end of the 90$^{th}$ day, the moisture increased to 15.46%, 15.25%, and 15.10% for air pack (control), vacuum pack, and nitrogen pack, respectively, with a significant difference ($p$<0.05). similarly. As noted by Todd (2003) [42], HDPE acts as a more effective barrier to both oxygen and moisture than LDPE bags, which helps in preserving the quality of the product during storage

In the present study, the protein content of solar tunnel dryer hurdle-processed dried shrimp was 71.09% for the untreated sample ($T_0S_{LD}$, $T_0S_{HD}$) and 71.61% for the treated sample ($T_1S_{LD}$, $T_1S_{HD}$). At the end of the storage period, the protein content decreased to 66.75%, 69.78%, 67.02% and 70.53% for $T_0S_{LD}$, $T_1S_{LD}$, $T_0S_{HD,}$ and $T_1S_{HD,}$ respectively. Findings within range have been reported by Gh *et al.* (2018) [46], the protein content in dried tiny shrimp (*Macrobrachium nipponense*) was found to be 73.74%. Similarly, Verma *et al.* (2024) [44] report that the protein content ranged from 70.30-71.12% of peeled dried shrimp dried using solar cum electric dryer and a microwave dryer. The reduction in crude protein content in dried fish samples may be attributed to the activity of endogenous enzymes and microorganisms, which break down protein macromolecules into smaller, volatile nitrogenous compounds, as noted by El-Soaid Basuni (1993) [18] and Bill and Shemkai (2006) [11].

At the beginning of the storage study of hurdle-processed shrimp dried using a solar tunnel dryer observed that the fat content was 3.43% for the untreated sample ($T_0S_{LD}$, $T_0S_{HD}$) and 3.75% for the treated sample ($T_1S_{LD}$, $T_1S_{HD}$). Fat content was decreased to 2.71%, 3.14%, 2.97%, and 3.22% for $T_0S_{LD}$, $T_1S_{LD}$, $T_0S_{HD}$ and $T_1S_{HD}$ respectively. The decrease in fat content was observed by Rabie *et al.* (2016) [34] and Gh *et al.* (2018) [46] with the increase in storage period. The control sample's fat loss was probably caused by ongoing lipid oxidation throughout drying and storage. As an antioxidant, citric acid helped lessen this effect by maintaining the fat content of treated samples while they were being stored.

The residue that remains after an organism has completely burned is called ash (Gopakumar, 2002) [19]. In the present study, ash content was 12.26% for the control sample ($T_0S_{LD}$, $T_0S_{HD}$) and 12.60% for the treated sample ($T_1S_{LD}$, $T_1S_{HD}$). The ash content was decreased to 10.61%, 11.08%, 10.76% and 11.37% at the end of the storage for $T_0S_{LD}$, $T_1S_{LD}$, $T_0S_{HD,}$ and $T_1S_{HD,}$ respectively. A similar trend of a decrease in ash content was observed by Bamble (2019) [7] for dry tiny shrimp and Jeyakumari *et al.* (2024) [23] on dried brined Bombay duck during a storage study. The osmosis process caused salt to infuse into the shrimp meat, increasing the ash level of the powder as the moisture content decreased (Zawawi *et al.* 2023) [47].

**Table 1:** Changes in proximate composition of hurdle-processed kiddi shrimp during storage study

| Attributes | Treatment | Storage days | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| Moisture | $T_0S_{LD}$ | 13.22±0.04 | 14.08±0.01 | 15.00±0.04 | 15.92±0.02 | 17.04±0.02 | 18.32±0.02 | 19.93±0.02 |
| | $T_1S_{LD}$ | 12.03±0.02 | 12.70±0.01 | 13.23±0.01 | 13.94±0.02 | 14.51±0.02 | 15.16±0.02 | 15.99±0.03 |
| | $T_0S_{HD}$ | 13.22±0.04 | 13.78±0.01 | 14.50±0.02 | 15.49±0.02 | 16.42±0.02 | 17.92±0.01 | 19.23±0.02 |
| | $T_1S_{HD}$ | 12.03±0.02 | 12.27±0.02 | 12.57±0.03 | 13.01±0.01 | 13.57±0.01 | 14.19±0.02 | 14.79±0.03 |
| Protein | $T_0S_{LD}$ | 71.09±0.01 | 70.58±0.02 | 69.99±0.03 | 69.45±0.01 | 68.83±0.02 | 68.83±0.02 | 66.75±0.02 |
| | $T_1S_{LD}$ | 71.61±0.01 | 71.21±0.01 | 71.01±0.02 | 70.61±0.01 | 70.37±0.02 | 70.08±0.02 | 69.78±0.02 |
| | $T_0S_{HD}$ | 71.09±0.01 | 70.78±0.02 | 70.38±0.03 | 69.65±0.02 | 69.03±0.02 | 68.02±0.02 | 67.02±0.02 |
| | $T_1S_{HD}$ | 71.61±0.01 | 71.52±0.01 | 71.41±0.01 | 71.21±0.01 | 71.04±0.02 | 70.82±0.02 | 70.53±0.01 |
| Fat | $T_0S_{LD}$ | 3.43±0.02 | 3.32±0.01 | 3.22±0.02 | 3.15±0.01 | 3.01±0.01 | 2.86±0.02 | 2.71±0.02 |
| | $T_1S_{LD}$ | 3.75±0.02 | 3.62±0.01 | 3.52±0.01 | 3.44±0.01 | 3.32±0.02 | 3.25±0.02 | 3.14±0.01 |
| | $T_0S_{HD}$ | 3.43±0.02 | 3.32±0.02 | 3.26±0.02 | 3.22±0.01 | 3.15±0.02 | 3.05±0.01 | 2.97±0.02 |
| | $T_1S_{HD}$ | 3.75±0.02 | 3.68±0.01 | 3.59±0.01 | 3.49±0.01 | 3.39±0.02 | 3.32±0.02 | 3.22±0.02 |
| Ash | $T_0S_{LD}$ | 12.26±0.02 | 12.01±0.02 | 11.78±0.02 | 11.47±0.02 | 11.11±0.03 | 10.82±0.01 | 10.61±0.03 |
| | $T_1S_{LD}$ | 12.60±0.01 | 12.46±0.01 | 12.23±0.01 | 11.99±0.02 | 11.79±0.03 | 11.49±0.02 | 11.08±0.02 |
| | $T_0S_{HD}$ | 12.26±0.02 | 12.11±0.02 | 11.85±0.02 | 11.63±0.02 | 11.39±0.01 | 11.00±0.01 | 10.76±0.01 |
| | $T_1S_{HD}$ | 12.60±0.01 | 12.52±0.01 | 12.41±0.03 | 12.28±0.01 | 11.99±0.01 | 11.65±0.02 | 11.37±0.02 |

Mean ± SD in the same column with significantly different ($p$<0.05) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## Changes in biochemical parameters of hurdle-processed kiddi shrimp during storage study

### Trimethylamine (TMA)

TMA content is very useful to determine the quality index for assessing the freshness of the fish and shrimp. The dried samples adhered to the permissible values of 10-15 mg/100 g (Connell, 1975) [15].

The present study shows that there was no significant difference in the TMA value of the control and citric acid-treated sample packed in LDPE and HDPE bags on the initial day (Day 0). The TMA content of Solar tunnel dryer dried hurdle processed shrimp packed in LDPE bags increased from 4.02 to 11.11 mg/100 g and 3.29 to 7.89 mg/100 g for $T_0S_{LD}$ and $T_1S_{LD,}$ and HDPE bags increased from 4.02 to 9.65 mg/100 g and 3.29 to 6.33 mg/100 g for

$T_0S_{HD}$ and $T_1S_{HD}$, respectively. Significant differences ($p \leq 0.05$) were observed in TMA values between different dried shrimp samples at any time of storage. The lowest TMA content was observed in the 0.6% citric acid-treated sample packed in an HDPE bag ($T_1S_{HD}$) after 90 days of storage at ambient temperature.

The results had similar trends with Bambale (2019) [7] for increasing TMA content of dried tiny shrimp packed in an HDPE bag with an increase in storage time. At the beginning of the storage, the TMA content was 4.917±0.86 (mg/100 g), which was increased to 17.817±0.67 (mg/100 g) on the 90th day. A similar observation was reported by Bhattacharya *et al.* (2016) [9]. During the storage period, the value for dry Bombay duck packed in LDPE bags increased from 11.89±1.87, 10.4±1.9, and 11.03±1.58 mg/100 g to 19.77±1.12, 24.82±1.4, and 14.88±1.37 mg/100 g at the end of the 90th day. The main source of the increase in TMA-N content is the breakdown of NPN (non-protein nitrogen) components such as TMAO by bacterial activity and certain intrinsic enzymes (Gram and Dalgaard, 2002) [20].

**Table 2:** Trimethylamine (TMA)

| Storage periods (day) | TMA (mg/100 g) | | | |
|---|---|---|---|---|
| | $T_0S_{LD}$ | $T_1S_{LD}$ | $T_0S_{HD}$ | $T_1S_{HD}$ |
| 0 | 4.02±0.02 | 3.29±0.03 | 4.02±0.02 | 3.29±0.03 |
| 15 | 4.96±0.02 | 3.97±0.02 | 4.57±0.02 | 3.55±0.03 |
| 30 | 5.88±0.03 | 4.68±0.02 | 5.25±0.02 | 4.01±0.02 |
| 45 | 6.99±0.03 | 5.00±0.03 | 6.37±0.02 | 4.47±0.02 |
| 60 | 7.99±0.03 | 5.86±0.01 | 7.56±0.04 | 5.06±0.02 |
| 75 | 9.01±0.02 | 6.67±0.03 | 8.34±0.03 | 5.75±0.01 |
| 90 | 11.11±0.02 | 7.89±0.02 | 9.65±0.02 | 6.33±0.02 |

Mean ± SD in the column with significantly different ($p<0.05$) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## Total volatile base-nitrogen (TVB-N)

The TVB-N content is a common way to evaluate marine products' freshness to assess the quality and progressive decline in shelf life. The dried samples adhered to the permissible values of TVB-N (100-200 mg/100 g) (Connell, 1995) [16].

In the present study, the TVB-N value on the 0th day of solar tunnel dryer dried hurdle processed shrimp was 14.20 mg/100 g for untreated sample packed in LDPE ($T_0S_{LD}$) and HDPE ($T_0S_{HD}$) bag; 13.21 mg/100 g for citric acid treated samples packed in LDPE ($T_1S_{LD}$) and HDPE ($T_1S_{HD}$) bag. After 90 90-day storage period, the value increased to 25.79 mg/100 g, 18.05 mg/100 g, 24.51 mg/100 g, and 16.55 mg/100 g for $T_0S_{LD}$, $T_1S_{LD}$, $T_0S_{HD}$, and $T_1S_{HD}$, respectively.

A similar trend was observed by Rabie *et al.* (2016) [34] in dried pink shrimp (*Pandalus borealis*) treated with 0.5% sodium bisulphate and 0.5% sodium tripolyphosphate by immersion method and dried by sun drying and packed in polyethylene bags. At the beginning of the storage study, the treated sample and control sample value ranges from 17.95-18.23 mg/100 g and 18.35 mg/100 g on the 0th day and increased to 25.60-25.73 mg/100 g and 30.91mg/100 g, respectively, on the 4 month of storage for the sun-dried sample. Similarly, the effect of Dry salt and 0.25% potassium sorbate, Saturated brine and 0.3% sodium benzoate (T2) and saturated brine (C) on Bombay duck (*Harpodon nehereus*) dried using sun drying packed in LDPE bags, shows a similar increasing trend for TVB-N content during storage of 120 days (Bhattacharya *et al.* 2016) [9]. On the 0th day, the TVB-N value was 24.79±1.6 mg/100 g, 26.09±1.07 mg/100 g, 19.67±1.07 mg/100 g for the brine sample, potassium sorbate (0.25%), sodium benzoate (0.3%), respectively. On the 90th day, the TVB-N value increased to 37.18±1.17 mg/100 g, 36.46±1.1 mg/100 g, and 29.72±1.71 mg/100 g for the brine sample, potassium sorbate (0.25%), and sodium benzoate (0.3%), respectively.

**Table 3:** Total volatile base-nitrogen (TVB-N)

| Storage periods (day) | TVB-N (mg/100 g) | | | |
|---|---|---|---|---|
| | $T_0S_{LD}$ | $T_1S_{LD}$ | $T_0S_{HD}$ | $T_1S_{HD}$ |
| 0 | 14.20±0.03 | 13.21±0.02 | 14.20±0.03 | 13.21±0.02 |
| 15 | 14.95±0.03 | 13.73±0.02 | 14.47±0.02 | 13.48±0.02 |
| 30 | 16.55±0.02 | 14.30±0.02 | 15.78±0.02 | 13.92±0.02 |
| 45 | 18.45±0.04 | 15.57±0.02 | 17.14±0.03 | 14.57±0.02 |
| 60 | 20.58±0.02 | 16.43±0.02 | 19.06±0.02 | 15.03±0.02 |
| 75 | 23.00±0.03 | 17.25±0.03 | 21.16±0.02 | 15.72±0.02 |
| 90 | 25.79±0.02 | 18.05±0.02 | 24.51±0.03 | 16.55±0.03 |

Mean ± SD in the same column with significantly different ($p<0.05$) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## pH

The change in pH mainly depends on the storage temperature (Hernandez *et al.* 2009) [22]. In the present study, the pH value is steadily increased in all hurdle-processed samples during the storage period. On the 0th day, the pH value was 6.77 and 6.01 for $T_0S_{LD}$, $T_0S_{HD}$, and $T_1S_{LD}$, $T_1S_{HD}$, respectively, with no significant difference. At the end of 90 days, the value increased to 7.52, 6.63, 7.39, and 6.40 for $T_0S_{LD}$, $T_1S_{LD}$ and $T_0S_{HD}$, and $T_1S_{HD}$, respectively. The result of the present study corroborates the finding of Rabie (2016) [34]. The pH value of the dried shrimp sample treated with sodium bisulphate (0.5%) and sodium tripolyphosphate (0.5%) and dried with sun drying was 6.12-6.55 and 6.28 for the treated and control sample, respectively, on the 0th day. As storage period increases, the pH value increases to 6.30-6.67 for treated and 6.49 for control at the end of 120 days. Alkali and Badau (2021) [3] observed that the pH value of smoked chicken treated with 0.2% citric acid was 5.46 on the initial day of storage, increased to 5.76 at the end of the storage period. In the present study, the pH value increased as the storage time increased. There was, however, a significant difference ($p<0.05$) in the pH of the dried shrimp sample between treatments throughout the storage period. According to Bala *et al.* (1979) [6], the breakdown of protein macromolecules into a tiny fraction of volatile nitrogenous chemicals may be the cause of the pH value increase during storage.

**Table 4:** pH

| Storage periods (day) | pH | | | |
|---|---|---|---|---|
| | $T_0S_{LD}$ | $T_1S_{LD}$ | $T_0S_{HD}$ | $T_1S_{HD}$ |
| 0 | 6.77±0.02 | 6.01±0.03 | 6.77±0.02 | 6.01±0.03 |
| 15 | 6.93±0.02 | 6.10±0.02 | 6.86±0.01 | 6.07±0.02 |
| 30 | 7.05±0.02 | 6.20±0.02 | 6.97±0.01 | 6.16±0.01 |
| 45 | 7.16±0.02 | 6.32±0.01 | 7.08±0.01 | 6.19±0.01 |
| 60 | 7.29±0.01 | 6.40±0.02 | 7.19±0.02 | 6.25±0.02 |
| 75 | 7.41±0.02 | 6.52±0.02 | 7.27±0.02 | 6.33±0.02 |
| 90 | 7.52±0.03 | 6.40±0.01 | 7.39±0.02 | 6.40±0.01 |

Mean ± SD in the same column significantly different ($p<0.05$) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## Peroxide value (PV)

The permissible limit of peroxide value is 10-20 meqO2/kg of fish oil (Connell 1995) [16]. In the present study, the PV value of untreated dried shrimp ($T_0S_{HD}$, $T_0S_{LD}$) and 0.6% citric acid ($T_1S_{HD}$, $T_1S_{LD}$) was 1.09 and 0.49 meqO2/kg, respectively, on the 0th day. At the end of storage of 90 days, the PV value increased to 2.17, 1.26, 1.91, and 0.95 for $T_0S_{LD,}$ $T_1S_{LD,}$ $T_0S_{HD,}$ and $T_1S_{HD,}$ respectively. The results of the experiment were consistent with studies done by Chowdhury *et al.* (2020) [12] on salted dried barb fish (*Puntius spp*.) packed in different packaging materials. On the initial day of storage, the PV value was 2.08 meqO2/kg for air pack, vacuum pack, and nitrogen pack samples. As the storage time increased, the value reached 6.76, 3.05, and 2.90 meqO2/kg of fat on the 90th day. In contrast with Bamble (2019) [7], the PV value of dried tiny shrimp packed in an HDPE bag on the 0th day was 2.993 meqO2/kg, increased to 22.08 meqO2/kg on the 90th day. Wu and Mao (2008) [45] indicated that the application of elevated temperatures during the drying procedure could enhance the decomposition of peroxides into carbonyl species, consequently resulting in a persistently low peroxide value. Increase of peroxide value may be attributed to the oxidation of highly unsaturated fatty acids in fish lipids by the catalytic activity of common salt, pro-oxidant action of moisture, and also auto-oxidation by atmospheric oxygen (Priyadarshini *et al.* 2012) [31].

**Table 5:** Peroxide value (PV)

| Storage periods (day) | PV (meqO2/kg of fat) | | | |
|---|---|---|---|---|
| | $T_0S_{LD}$ | $T_1S_{LD}$ | $T_0S_{HD}$ | $T_1S_{HD}$ |
| 0 | 1.09±0.02 | 0.49±0.02 | 1.09±0.02 | 0.49±0.02 |
| 15 | 1.19±0.02 | 0.58±0.02 | 1.16±0.01 | 0.54±0.01 |
| 30 | 1.33±0.02 | 0.71±0.02 | 1.23±0.02 | 0.62±0.02 |
| 45 | 1.50±0.03 | 0.87±0.02 | 1.37±0.02 | 0.71±0.02 |
| 60 | 1.68±0.02 | 1.02±0.03 | 1.53±0.02 | 0.77±0.02 |
| 75 | 1.89±0.02 | 1.61±0.02 | 1.70±0.03 | 0.87±0.01 |
| 90 | 1.26±0.02 | 1.84±0.02 | 1.91±0.02 | 0.95±0.02 |

Mean ± SD in the same column with significantly different ($p<0.05$) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## Salt content

Salt content is a key parameter in evaluating the quality of salted products, as it significantly influences their sensory attributes, shelf life, and overall safety (Thorarinsdottir *et al.* 2004) [40]. In the present experiment, the salt content was steadily decreased throughout the storage period. On the 0th day, the salt content for the control sample ($T_0S_{LD,}$ $T_0S_{HD}$) and 3.63% for the treated sample ($T_1S_{LD,}$ $T_1S_{HD}$) on the 0th day. At the end of the storage period, the value decreased to 2.62%, 3.02%, 2.76%, and 3.13% for $T_0S_{LD,}$ $T_1S_{LD,}$ $T_0S_{HD,}$ and $T_1S_{HD,}$ respectively. A similar trend was observed by Kumar *et al.* (2013) [26] for dried salted kursa (*Labeo gonius*) dried by sun and oven, dried packed in a corrugated box and gunny bag were 17.53% and 19.02% respectively. At the end of the 90th day, the salt content (%) was 15.67%, 14.74%, 16.36% and 15.62% for KSC, KSG, KOC, and KOG. Similarly, Chavan (2004) [12] reported that the salt content of dried salted ribbon fish (*Lepturacanthus savala*) packed in trend pack was decreased from 15.85%, 15.50%, 15.80% and 12.60% to 15.10%, 15.10%, 15.12% and 11.60% for STD, RBP, BPS, and MS. Niamnuy *et al.* (2007) [28], with a study on quality changes of shrimp during boiling in salt solution reported that the salt absorption content in the shrimp meat increased with increasing the boiling time (min). The salt content (%) of dried shrimp decreased as the storage period increased. It may be because of an increase in the moisture content of dried shrimp packed in LDPE and HDPE bags.

**Table 6:** Salt content

| Storage periods (day) | Salt content (%) | | | |
|---|---|---|---|---|
| | $T_0S_{LD}$ | $T_1S_{LD}$ | $T_0S_{HD}$ | $T_1S_{HD}$ |
| 0 | 3.84±0.02 | 3.63±0.01 | 3.84±0.02 | 3.63±0.01 |
| 15 | 3.62±0.01 | 3.58±0.02 | 3.64±0.01 | 3.58±0.02 |
| 30 | 3.42±0.01 | 3.47±0.01 | 3.45±0.01 | 3.51±0.02 |
| 45 | 3.24±0.01 | 3.35±0.01 | 3.31±0.01 | 3.41±0.02 |
| 60 | 3.02±0.02 | 3.25±0.01 | 3.13±0.02 | 3.30±0.02 |
| 75 | 2.82±0.01 | 3.17±0.02 | 2.96±0.01 | 3.20±0.02 |
| 90 | 2.62±0.01 | 3.02±0.02 | 2.76±0.01 | 3.13±0.02 |

Mean ± SD in the same column with significantly different ($p<0.05$) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## Changes in Microbial quality of hurdle-processed kiddi shrimp during storage study

### Total Plate Count (TPC)

The total bacterial count is a crucial metric for estimating a product's shelf life and evaluating its microbiological quality. Food's nutritional makeup and physical factors, such as temperature and the surrounding climate, affect microbial activity (Gram *et al.* 2002) [21]. The acceptable microbiological standard of dried shrimp (total number of microorganisms of not more than $10^5$ organisms/g sample (TISI 2004) [41].

In the present study, the total plate count of all samples was gradually increased with the increase in storage time. On the 0th day, the TPC count of shrimp dried was 3.43 log cfu/g for the untreated sample packed in LDPE ($T_0S_{LD}$) and HDPE ($T_0S_{HD}$) bags; 2.88 log cfu/g for citric acid-treated samples packed in LDPE ($T_1S_{LD}$) and HDPE ($T_1S_{HD}$) bags on the initial day. The TPC count was increased to 4.35, 3.33, 4.21, and 3.22 log cfu/g on the 90th day for $T_0S_{LD}$, $T_1S_{LD}$, $T_0S_{HD}$, and $T_1S_{HD}$, respectively. The results agree with those reported by Jeyakumari (2024) [23] for dried Bombay duck treated with acetic acid, chitosan dissolved acetic acid, malic acid, and chitosan dissolved malic acid, which ranged between 3.6-3.9 log cfu/g and showed an increasing trend during storage time. According to Chowdhary *et al.* (2020) [14] for dried barb was packed in different packaging materials. The TPC count on the 0th day was 4.29 Log cfu/g. At the end of the 90th day, the TPC count was increased to 6.88, 6.01, and 6.29 Log cfu/g for air pack, vacuum pack, and nitrogen pack samples. Niamnuy *et al.* (2007) [28] found that with increasing boiling time and using more salt concentrations, the total number of microorganisms in the final product would be reduced. HDPE containers offer a barrier against moisture and oxygen in addition to protection against dust, insects, bacteria, and germs, according to Todd (2003) [42].

**Table 7:** Total Plate Count (TPC)

| Storage periods (day) | TPC (log CFU/g) | | | |
|---|---|---|---|---|
| | $T_0S_{LD}$ | $T_1S_{LD}$ | $T_0S_{HD}$ | $T_1S_{HD}$ |
| 0 | 3.43±0.03 | 2.88±0.01 | 3.43±0.03 | 2.88±0.01 |
| 15 | 3.52±0.01 | 2.92±0.01 | 3.49±0.02 | 2.91±0.02 |
| 30 | 3.62±0.02 | 2.99±0.03 | 3.53±0.01 | 2.96±0.02 |
| 45 | 3.74±0.02 | 3.06±0.02 | 3.66±0.02 | 3.03±0.01 |
| 60 | 3.93±0.02 | 3.16±0.01 | 3.84±0.02 | 3.08±0.01 |
| 75 | 4.15±0.03 | 3.23±0.01 | 4.04±0.02 | 3.16±0.01 |
| 90 | 4.35±0.03 | 3.33±0.01 | 4.21±0.04 | 3.22±0.01 |

Mean ± SD in the same column with significantly different ($p<0.05$) (n = 3) with respect to sampling days. $T_0S_{LD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_1S_{LD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer, and stored in LDPE bags; $T_0S_{HD}$: Kiddi shrimp treated with 0% citric acid, dried using solar tunnel dryer and stored in HDPE bags; $T_1S_{HD}$: Kiddi shrimp treated with 0.6% citric acid, dried using solar tunnel dryer and stored in HDPE bags

## Conclusion

The present study showed the development of shelf-stable, microbiologically safe dried kiddi shrimp using a combination of hurdle treatments such as dipping in citric acid, blanching using 5% NaCl, and drying using a hygienic solar dried method. The shrimp treated with 0.6% citric acid and packed in an HDPE bag ($T_1S_{HD}$) show high acceptance at the end of the 90-day storage period at ambient temperature.

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