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Research Article

Effect of Traditional Ageing Practices on Physicochemical, Phytochemical, and Sensory Attributes of *Bor-thekera (Garcinia pedunculata* Roxb.*)*

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Abstract: Traditional sun-drying of Bor-thekera (*Garcinia pedunculata* Roxb.) fruit slices for consumption and long-term storage are practiced in Assam and other Northeastern states of India. The indigenous communities of the region have a long-held belief that the medicinal value of the dried slices increases with ageing. However, there are limited studies that bridge the gap between this indigenous knowledge with food science. The present study, therefore, aims to investigate the effects of ageing on physicochemical, functional, phenolic, antioxidant, and sensory attributes of traditionally processed Bor-thekera slices. Fresh-dried (FDGP; collected in April 2025) and stored-dried *Garcinia pedunculata* (SDGP; collected in April 2021) samples were studied. The total phenolic content (6.23 ± 0.018 mg GAE/g) and DPPH scavenging activity (76.54 ± 0.156%) revealed that the SDGP samples retained significantly higher phenolic content than FDGP samples ($p < 0.05$); cold-water extraction minimized the degradation or loss of heat-sensitive compounds. The functional integrity of the samples was supported by FTIR spectra. Sensory assessment involving a limited panel size demonstrated that the taste and color of SDGP water infusions were preferable and received good overall acceptability. Thus, these findings scientifically relate to the traditional belief on the ageing of sun-dried Bor-thekera, providing partial scientific support for its stability and potential functional value.

Keywords: *Garcinia pedunculata*; sun-drying; indigenous knowledge; phenolic content; antioxidant activity

1. Introduction

Garcinia pedunculata Roxb. (Bor-thekera) is consumed in Assam and other Northeastern states of India as a dried souring agent and traditional medicine [1]. These fruits, belonging to the Clusiaceae family, are available from April to May. The fruit is locally known as Bor-thekera in Assam [2]. It holds an important place in the traditional practices of the indigenous communities. The sun-dried slices are used in culinary preparations of curries such as “Masor tenga” (sour fish curry) and lentils. These sun-dried slices have a long history in ethnobotanical knowledge as traditional medicine [1,3]. It is used for various gastrointestinal and anti-inflammatory ailments, which reflect deeply rooted cultural knowledge of food and medicine synergies [4]. In some regions, it is also used in pickling meat and fish items [4]. During Bohag Bihu, one of the most celebrated festivals of the Assamese community, chopped Bor-thekera slices are arranged on skewers along with other vegetables like gourd, brinjal, etc. These bamboo skewers are given to the cattle in the ritualistic bathing. The leftover pieces are eaten as mixed vegetable curry or with lentils [5].

The fruit is highly acidic, and the most common methods for consumption and preservation are in the form of dried slices [1]. The slices are sun-dried for 10 to 15 days [5]. Sun-dried Bor-thekera slices can be stored for years without the addition of any kind of preservatives. Its medicinal properties are believed to increase as it ages [1]. *Garcinia pedunculata* is reported to contain various bioactive compounds, which include phenolic acids, xanthones, benzophenones, flavonoids, organic acids like (−)-hydroxycitric acid, which are associated with its antioxidant, antimicrobial, anti-inflammatory, cardioprotective, weight management, hepatoprotective, and other therapeutic properties [6–10].

(a) (b)

Figure 1. (a) Fresh-Dried *Garcinia pedunculata* (FDGP), and (b) Stored-Dried *Garcinia pedunculata* slices

Conventional drying and storage practices serve as inexpensive and sustainable ways of food preservation [2,5]. Research on fruits and medicinal plants often highlights drying and storage as important factors in the stability and concentration of phytochemicals [11,12]. For instance, the deterioration or the increase in extractability of phenolic compounds may occur as the phytocompounds age. Research on fruits and vegetables has mostly focused on the antioxidant potential and the phenolic content in freshly processed fruit matrices, or lyophilized samples [8,11]. Despite its traditional relevance, systematic evaluation of the impact of long-term storage and ageing practices the quality of traditionally dried *Garcinia pedunculata* is limited. Although phytochemical and antioxidant properties of Garcinia species have been studied extensively [13,14]. Limited studies in specialized literature have reported the effect of traditional drying practices and storage on physicochemical and phytochemical properties of the dried slices. Comparative studies on ageing practices with respect to fresh-dried samples and their biochemical, antioxidant, and functional characteristics of Bor-thekera are limited.

The present study aims to investigate the effects of prolonged storage in traditionally dried Bor-thekera slices on their phenolic content, antioxidant activity, physicochemical characteristics, and functional properties. It involves a comparative analysis between samples collected in April 2021, stored-dried (SDGP), stored for four years, and fresh-dried *Garcinia pedunculata* (FDGP) samples collected in April 2025, dried under open sun drying conditions. This study attempts to integrate standard analytical methods, sensory evaluation, and traditional knowledge. Total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activities (DPPH and ABTS scavenging activity) of both the samples were studied using cold water (CW) and hot water (HW) as extraction solvents. Physicochemical and functional parameters of SDGP and FDGP were evaluated. FTIR spectra of both the samples were studied. This research focuses on relating scientific findings with indigenous beliefs, connecting food science and ethnobotanical knowledge.

2. Materials and Methods

2.1. Sample Collection and Preparation

Garcinia pedunculata fruits were collected from Puthimari village, Tezpur (26.62° N,92.78° E), Assam, India, in April 2021 and April 2025. The collected samples were authenticated at Gauhati University Botany Herbarium (GUBH) and specimens were submitted for future reference under Reference No. Herb. /GUBH/2025/096. Ripe fruits were selected for the study. The initial moisture content of the fruits ranged from 88.21–89.11% (wet basis). Fruits collected in April 2021 were washed, sliced into 3 ± 0.5 mm thickness using a clean stainless-steel knife, and slice thickness was measured using Vernier callipers (Mitutoyo, Absolute). The cut slices were subjected to traditional open-sun conditions for 10 to 15 days to achieve sufficient moisture reduction suitable for storage (11.34–13.56%) [8]. Two kinds of samples were considered for the study:

2.1.1. Stored-Dried Garcinia pedunculata (SDGP)

Sample prepared in April 2021, and stored for 4 years, under laboratory conditions (Figure 1b). The dried slices were stored in clean airtight containers under typical household ambient conditions (25 ± 3 °C, 60 ± 5 % RH) prevalent in Tezpur, Assam, India, characterized by seasonal variations. The samples were stored in dark conditions with occasional exposure to indirect daylight. These conditions reflected typical traditional storage practices in the households in Assam.

2.1.2. Fresh-Dried Garcinia pedunculata (FDGP)

The fruits collected in April 2025 were subjected to the same processing conditions (Figure 1a). The FDGP slices were analyzed shortly after drying.

2.2. Physicochemical Properties

2.2.1. Moisture Content

Moisture content of the fresh-dried (FDGP) and stored-dried (SDGP) *Garcinia pedunculata* samples was measured using the hot-air oven method (Equitron, Ecogain Series) [15]. A 5.0 g sample was placed in a hot-air oven at 105 ± 2 °C for 24 h. The samples were cooled in a desiccator, and the weight was measured using a digital weighing balance (ME204, Mettler Toledo). Moisture content was calculated using the formula given in Eq. (1).

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

where W_1= initial weight of sample (g), and W_2= final dry weight of sample (g)

2.2.2. pH

The pH of the samples was measured using a digital pH meter (Ph 700, Eutech). A 10% (w/v) sample was prepared by dispersing 2 g of the sample in 50 mL of distilled water. The

sample solution was left undisturbed overnight. The pH meter was calibrated using standard buffer solutions (pH 4.0 and 7.0) before taking the measurement. The pH of the samples was recorded at room temperature [15].

2.2.3. Titratable Acidity

Titratable acidity was determined following the acid–base titration method. A 2% (w/v) sample extract was prepared by homogenising 2 g of the sample with 100 mL of distilled water and filtering the mixture. An aliquot of 10 mL of the filtrate was titrated against 0.1 N NaOH using phenolphthalein as an indicator until a persistent light pink endpoint was observed [16]. Titratable acidity was expressed as a percentage of citric acid equivalent and calculated using the following Eq. (2).

$$\text{Titratable acidity (\%)} = \frac{V \times N \times E \times 100}{W \times 1000} \quad (2)$$

Where V = volume of NaOH used (mL), N = normality of NaOH, E = equivalent weight of citric acid (64), and W = weight of sample (g) present in the aliquot titrated

2.2.4. Total Soluble Solids (TSS)

Total soluble solids were measured using a handheld digital refractometer and expressed as °Brix. A small quantity of sample extract was prepared using 2 g of the sample in 100 mL of distilled water. A few drops of the clear filtrate were placed on the refractometer prism, and the reading was recorded [15].

2.2.5. Vitamin C Content

The vitamin C content of fresh-dried (FDGP) and stored-dried (SDGP) samples was determined by 2,6-dichlorophenolindophenol (DCPIP) titrimetric method. Sample preparation involved extraction of 1 g of dried powder with 20 mL of 3% metaphosphoric acid. 10 mL of the clear aliquot was titrated against DCPIP until persistent pink color was obtained [15]. Vitamin C was calculated using Eq. (3) and expressed as mg per 100g dry weight (DW) of the sample.

$$Vitamin\ C = \frac{V \times F \times DF \times 100}{W} \quad (3)$$

where V is volume of DCPIP dye consumed by the sample (mL), F is dye factor (mg of ascorbic acid equivalent to 1 mL of DCPIP), DF is the dilution factor of the sample extract, and W is weight of the dried sample (g)

2.2.6. Color Measurement

The color of FDGP and SDGP slices was measured using a Hunter Lab colorimeter (UltraScan Vis). The instrument was calibrated before taking the measurements. Samples were placed in clean transparent polypropylene bags, and color was recorded in terms of lightness (L*), redness/greenness (a*), and yellowness/blueness (b*). Measurements were taken in triplicate [8].

2.3. Phytochemical Analysis

2.3.1. Preparation of Sample

Hot and cold-water extracts of the sample were prepared for the analysis to simulate traditional consumption practices of Bor-thekera, where dried slices are either soaked in cold water overnight or incorporated into curries during the final stage of preparation subjected to brief boiling for 5–10 min. 2 g of dried slices (FDGP and SDGP) were soaked in 100 mL of cold distilled water and kept for 24 h with occasional shaking. Similarly, 2 g of dried slices were boiled in 100 mL of distilled water for 10 min and cooled. Both the samples (cold and hot water) were filtered by using Whatman No.1 filter paper and stored at 2–8 °C for further analysis.

2.3.2. Total Phenolic Content (TPC)

TPC was measured by the Folin-Ciocalteu method with minor modifications [13]. 1.5 mL of Folin-Ciocalteu reagent (diluted tenfold) was added to 0.3 mL of the sample at room temperature for 2 min. To this, 1.2 mL of 7.5% (w/v) freshly prepared solution of sodium carbonate was added and kept undisturbed at room temperature for a period of 30 min. The measurements were taken at 765 nm (Cary 60 UV-Vis, Agilent Technologies). TPC was determined by reference to a Gallic acid (GA) standard curve and was expressed in terms of mg of GAE per g of dried fruit weight.

2.3.3. Total Flavonoid Content (TFC)

TFC was estimated by the aluminium trichloride ($AlCl_3$) method [13]. To 0.5 mL of the extract, 1 mL of 2% aluminium trichloride ($AlCl_3$) in methanol was added, followed by the addition of 1 mL of 1M sodium acetate. The absorbance was measured at 415 nm after a reaction time of 10 min (Cary 60 UV-Vis, Agilent Technologies). Quercetin was taken as the standard for the study, and the values obtained were expressed as mg Quercetin equivalent (QE) per g dried fruit weight.

2.3.4. 2,2-Diphenyl-1-picrylhydrazyl Radical Scavenging Activity (DPPH RSA)

DPPH radical scavenging activity of the extracts was determined by the DPPH method with minor modification [13]. 0.1 mM DPPH in methanol was freshly prepared. Samples extract and DPPH solution were mixed in a 1: 3 ratio, followed by vortexing for proper mixing. It was kept undisturbed in the dark at room temperature. The measurements were taken at 517 nm (Cary 60 UV-Vis, Agilent Technologies) after 30 min of incubation. Measurements were carried out in triplicate. Radical scavenging activity (RSA) was calculated in Eq. (4).

$$\text{DPPH RSA (\%)} = \frac{A_c - A_s}{A_c} \times 100 \tag{4}$$

where A_c and A_s are the absorbance of control and sample, respectively

2.3.5. 2,2'-Azino-bis(3-ethylbenzothiazoline 6-sulfonic acid) Radical Scavenging Activity (ABTS RSA)

For ABTS radical scavenging activity, the assay $ABTS^{\bullet+}$ cation radical was prepared by mixing 7 mM ABTS solution prepared in phosphate buffer of pH 7.4 (5 mM NaH_2PO_4, 5mM Na_2HPO_4, and 154 mM NaCl) with 2.45 mM potassium persulfate at a 1:1 ratio. The reaction mixture was kept undisturbed in the dark for 12–16 h at room temperature. Dilutions of the $ABTS^{\bullet+}$ solution to obtain 0.700 at 734 nm (Cary 60 UV-Vis, Agilent Technologies) were made with ethanol for the assay. For the scavenging activity, 200 µL of sample extract was mixed with 2.8 mL diluted $ABTS^{\bullet+}$ solution, and the absorbance was read after 5 min [11]. All measurements were conducted in triplicate. The percentage inhibition at 734 nm was calculated by the Eq. (5).

$$\text{ABTS RSA (\%)} = \frac{A_c - A_s}{A_c} \times 100 \tag{5}$$

where A_c (ABTS radical + ethanol) and A_s (ABTS radical + sample extract) represents absorbance of control used and sample, respectively

2.4. Functional Properties

2.4.1. Water Holding Capacity (WHC)

The water holding capacity of the FDGP and SDGP was determined by using a modified gravimetric method. 1.0 g of dried *Garcinia pedunculata* slice powder was weighed and transferred into a centrifuge tube (pre-weighed). It was then mixed with 10 mL of distilled water. The mixture was vortexed for 1 min and allowed to stand undisturbed at room temperature for 30 min. The samples were centrifuged at 1500 × g (Sorvall ST8R, Thermo Scientific) for 15 min. The supernatant was carefully discarded, and the weight of the residue was measured [17]. WHC was expressed as grams of water retained per gram of dry sample and was calculated using Eq. (6).

$$\text{WHC (g/g)} = \frac{W_2 - W_1}{W_1} \tag{6}$$

where W_1= initial weight of dry sample (g), and W_2= weight of sample after water absorption (g)

2.4.2. Oil Holding Capacity (OHC)

1.0 g of sample was mixed with 10 mL of edible oil (soybean oil) in a centrifuge tube. The mixture was then vortexed for 1 min and kept undisturbed for 30 min at room temperature. This was followed by centrifugation at 1500 × g (Sorvall ST8R, Thermo Scientific) for 15 min; the supernatant was carefully decanted; and the weight of the residue was measured [18]. The OHC was calculated using Eq. (7)

$$\text{OHC (g/g)} = \frac{W_2 - W_1}{W_1} \tag{7}$$

where W_1= initial dry sample weight (g) and W_2= weight after oil absorption (g)

2.4.3. Rehydration Ratio (RR)

2.0 g FDGP and SDGP samples were boiled in 100 mL distilled water and 2% salt solution for 15 min. It was removed carefully, and the excess surface water was gently drained without applying pressure with the help of blotting paper [19]. The weight of the rehydrated sample was recorded, and the rehydration ratio was calculated using Eq. (8)

$$\text{Rehydration ratio(RR)} = \frac{W_2}{W_1} \tag{8}$$

where W_1= initial dry sample weight (g) and W_2= weight after water absorption (g)

2.4.4. Swelling Index (SI)

The swelling index (SI) of FDGP and SDGP slices was determined on the basis of weight gain by the slices upon hydration. 2.0 g of slices was immersed in 100 mL of distilled water overnight, undisturbed. After 24 h the slices were carefully removed and gently blotted to remove the surface water, and weighed [17]**.** SI was calculated using Eq. (9)

$$\text{Swelling Index (\%)} = \frac{W_f - W_i}{W_i} \times 10 \tag{9}$$

where W_i= initial dry weight and W_f= weight after swelling and blotting

2.5. Fourier Transform Infrared (FTIR)

The pellet of dried fruit powder with potassium bromide (KBr) was prepared in a 1:10 w/w ratio. The FTIR spectrophotometer (Thermo Scientific, USA; Nicolet Instruments 410 FTIR) was operated at 400–4000 cm^{-1} frequency range and 4 cm^{-1} resolution for scanning the pellet. The measurements were done in transmittance mode [8].

2.6. Sensory Evaluation

The sensory evaluation was conducted with a limited panel size for assessment of consumer acceptability rather than a detailed analysis. A 9-point hedonic scale sensory evaluation was conducted to assess the acceptability and perceived sensory attributes of FDGP and SDGP infused water [20]. A small semi-trained panel of 10 participants familiar with the traditional culinary and medicinal uses of Bor-thekera (*Garcinia pedunculata*) was used for exploratory analysis. The sensory evaluation involved a non-invasive food product, and formal ethical approval was not required. The samples were given to the participants in a coded manner. 2 g of dried slices was soaked in 100 mL of drinking water and kept overnight for evaluation. All the panelists evaluated the samples for aroma, sourness, bitterness, and overall acceptability [21]. Tasting was performed without swallowing. The panelists rinsed their mouths with water before and between the samples.

The attributes were rated based on a 9-point hedonic scale, where 1 indicated “dislike extremely,” and 9 indicated “like extremely”. The results were expressed as mean ± standard deviation.

2.7. Statistical Analysis

The experiments were performed in triplicate and expressed as mean ± standard deviation. Statistical significance between samples was determined using independent t-test, paired sample t-test for sensory analysis and two-way ANOVA was used for phytochemical study. (SPSS software, Version 26) ($p < 0.05$).

3. Results and Discussion

3.1. Physicochemical and Functional Properties

The physicochemical properties of fresh-dried (FDGP) and stored-dried (SDGP) *Garcinia pedunculata* samples are given in Table 1. Independent samples t-test revealed significant differences ($p < 0.05$) between the two sample parameters. The results indicated that the moisture content of the SDGP (15.11 ± 0.86 %) was significantly higher than that of the FDGP samples (11.34 ± 0.31%) [t (4) = −7.18, $p = 0.002$]. However, the initial moisture content of dried SDGP samples was 13.56 ± 0.56% (April 2021). The increase in moisture content during the ageing period may be attributed to the gradual moisture absorption from ambient environmental conditions. The difference in the initial moisture content of fresh-dried batches (FDGP: 11.34 ± 0.31% and SDGP: 13.56 ± 0.56%) can be associated with the inherent variability of open sun drying conditions. Unlike controlled drying systems, sun drying is influenced by environmental factors, seasonal fluctuations, and year-to-year climatic differences, along with it variations in the raw material's initial moisture content, which plays a major role [22,23]. Therefore, such variations are expected in traditional conditions and do not indicate inconsistency in the processing. Although the moisture content of the SDGP samples (15.11 ± 0.86%) was relatively high, a study by Borah et al. (2025) reported comparable values (13–16%) for dried *Garcinia pedunculata* as a safe moisture range for storage [8,24]. Studies on other dried fruit, such as mango and apricot, reported moisture content of 15–16.8% as safe for storage [25,26]. The highly acidic pH (1.6–1.7) of the samples may inhibit the growth of spoilage microorganisms, contributing to their stability [27,28]. However, microbiological analysis may help in the evaluation of microbial safety and shelf-life under prolonged storage conditions.

The pH values of water infusions of both samples reflected the acidic nature of the infusions. The pH of the FDGP (1.79 ± 0.02) showed a statistically significant increase as compared to SDGP (1.67 ± 0.01) [t (4) = 10.75, $p < 0.001$]. This indicates increased acidity in the SDGP samples during the storage period. The titratable acidity (% citric acid) of SDGP samples (2.61 ± 0.05 %) was significantly higher than that of FDGP samples (1.95 ± 0.03%) [t = −19.61, $p < 0.001$]. This increase in titratable acidity may be due to concentration or release of organic acids during the storage period [16]. On the other hand, a negative impact on the Vitamin C content of Bor-thekera slices was observed due to drying and prolonged storage. The results demonstrated that the Vitamin C content of FDGP samples (79.56 ± 6.12 mg/100 g DW) was significantly higher than the SDGP samples (3.80 ± 0.11 mg/100 g DW) [t (4) = 21.43, $p < 0.001$], indicating that drying, long-term storage and ageing led to a substantial degradation of Vitamin C content.

The TSS values of SDGP (1.84 ± 0.05 °Brix) were significantly higher than those of FDGP (1.56 ± 0.06 °Brix) [t (4) = −6.68, $p = 0.003$]. Due to long-term storage, the cell wall

polysaccharides and pectin substances undergo gradual weakening. This facilitated the release of soluble sugars and organic acids, which may be attributed to an increase in TSS value [29]. The colour study of the slices revealed a significant difference between the FDGP and SDGP samples ($p < 0.05$). The colour parameters revealed that the L* (lightness) values of FDGP samples were significantly higher (L* = 41.03 ± 3.60) than the SDGP samples (L* = 19.21 ± 1.50) [t (4) = 9.70, p = 0.001], indicating darkening of the Bor-thekera slices due to ageing. The a* (redness/greenness) values of FDGP (a* = 4.08 ± 0.28) were higher than the SDGP samples (a* = 2.08 ± 0.26) [t (4) = 9.01, $p = 0.001$], indicating loss of red chromaticity during ageing. Similarly, the b* (yellowness/blueness) values of FDGP (b* = 7.32 ± 1.24) were higher than the SDGP samples (b* = 1.56 ± 0.13) [t (4) = 8.02, $p = 0.001$], indicating a gradual decline in the yellow pigments [8].

The functional properties of SDGP and FDGP also revealed significant differences (Table 1). The swelling index (SI) of the FDGP samples (64.13 ± 1.90) was significantly higher than that of the SDGP samples (30.67 ± 0.15) [t (4) = 30.40, $p < 0.001$], indicating structural relaxation and partial collapse of the structure which reduces the availability of hydrophilic binding sites [30]. The water holding capacity (WHC) showed similar results. The WHC of FDGP samples (1.74 ± 0.09) was significantly higher than the SDGP samples (1.37 ± 0.12) [t (4) = 4.46, $p = 0.011$]. The rehydration ratio (RR) of SDGP (1.16 ± 0.05) also reduced in comparison to FDGP (1.51 ± 0.02) [t (4) = 11.71, $p < 0.001$]. The integrity of the plant cellular matrix plays a role in these functional properties. Intact polysaccharide framework, porous and open structure in fresh-dried samples facilitated water absorption, whereas in the case of stored dried samples, there is rigidification and polymerization of the matrix [31]. The oil holding capacity (OHC) of FDGP (1.26 ± 0.05) and SDGP (1.17 ± 0.06) [t (4) = 2.17, $p = 0.096$] did not differ significantly, reflecting that ageing did not impact the lipid binding ability of fruit slices.

Table 1. Physicochemical and functional properties of Fresh-Dried (FDGP) and Stored-Dried (SDGP) Bor-thekera (*Garcinia pedunculata*)

Parameter	FDGP	SDGP
Moisture content (%)	11.34 ± 0.31	15.11 ± 0.86
pH	1.79 ± 0.02	1.68 ± 0.01
Titratable acidity (% citric acid)	1.95 ± 0.03	2.61 ± 0.04
Vitamin C (mg/100 g DW)	79.56 ± 6.12	3.80 ± 0.11
Total soluble solids (°Brix)	1.55 ± 0.05	1.83 ± 0.04
L*	41.03 ± 3.60	19.21 ± 1.50
a*	4.08 ± 0.28	2.08 ± 0.26
b*	7.32 ± 1.24	1.56 ± 0.13
Water holding capacity (g/g)	1.73 ± 0.08	1.36 ± 0.11
Oil holding capacity (g/g)	1.26 ± 0.04	1.16 ± 0.05
Rehydration ratio	1.51 ± 0.02	1.16 ± 0.05
Swelling index (%)	62.66 ± 6.52	30.16 ± 2.51
Values are mean ± SD (n = 3). Differences were evaluated using independent samples t-test ($p < 0.05$)		

3.2. Phytochemical Properties and Antioxidant Activity

The phenolic content and antioxidant activity of FDGP and SDGP samples are presented in Table 2. The effect of storage period and temperature on TPC, TFC, antioxidant activity (DPPH and ABTS scavenging activity) of the FDGP and SDGP samples was evaluated

using two-way ANOVA. The homogeneity of variances for all the responses was confirmed by Levene's test ($p > 0.05$). Partial eta squared (η^2) values were interpreted based on conventional thresholds, where values greater than 0.14 indicate a large effect size [32]. The results demonstrated that the phenolic content and antioxidant activities were significantly influenced by the ageing process and temperature of the extraction solvent ($p < 0.001$). The mean TPC content of SDGP samples (6.15 ± 0.004 mg GAE/g) was higher than that of FDGP (6.06 ± 0.004 mg GAE/g) ($p < 0.001$). The observed effect size ($\eta^2 = 0.970$) indicated substantial influence of the storage period, demonstrating a dominant influence on the total phenolic content of the dried slices. The slight increase in TPC of SDGP samples can be attributed to the fact that long-term storage induces certain biochemical and structural changes in the fruit matrix [29,33]. The release of bound phenolic compounds into a more extractable form due to the breakdown of phenolic-polysaccharides or phenolic-protein associations may occur. Depolymerization or oxidation of high polymeric weight phenolic into low polymeric weight compounds might occur, thereby contributing to the increased TPC content of SDGP samples [29,33].

The temperature of the extraction solvent used (CW and HW) also had a significant effect on the TPC content ($p < 0.001$). The cold-water extracts (CW) showed higher TPC (6.27 ± 0.004 mg GAE/g) than the hot water extracts (HW; 5.94 ± 0.004 mg GAE/g). The temperature of the extraction solvent exhibited a very large effect size ($\eta^2 = 0.997$), indicating significant influence on the total phenolic content, reflecting a strong effect size. Although the interaction effect between the storage period and temperature of extraction solvent was marginally significant ($p = 0.050$), the corresponding effect size ($\eta^2 = 0.400$) showed substantial influence. The results indicated that the TPC content of SDGP (6.307 ± 0.006 mg GAE/g) in CW was highest, while FDGP (5.893 ± 0.006 mg GAE/g) in HW showed the lowest TPC among the tested samples. The findings indicated that the TPC content was influenced by the ageing of the slices, and milder extraction conditions favored the phenolic retention and release in *Garcinia pedunculata.* Although high temperature of the extraction solvent promotes mass transfer, thermolabile phenolic compounds undergo oxidation, thermal degradation, or structural modification at very high temperatures [29,34].

The mean TFC of FDGP (2.97 ± 0.013 mg QE/g) was significantly higher than that of SDGP (2.81 ± 0.013 mg QE/g) ($p < 0.001$). The partial eta squared value ($\eta^2 = 0.906$) indicated a large effect size, demonstrating a pronounced impact of storage on the flavonoid content. The results suggest a possible decline in the TFC content during the ageing process. Flavonoids are chemically less stable and are more prone to oxidation, degradation, and polymerization than other phenolic compounds [29]. Similar to TPC, the CW extracts yielded higher TFC (3.09 ± 0.013 mg QE/g) than the HW (2.70 ± 0.013 mg QE/g) ($p < 0.001$). The analysis showed that the temperature of the extraction solvent ($\eta^2 = 0.983$) had a substantial influence on TFC recovery. The interaction effect was not significant ($p = 0.303$). Overall, it was observed that FDGP samples prepared in CW yielded the highest TFC (3.16 ± 0.018 mg QE/g), while SDGP samples in HW showed the lowest TFC (2.61 ± 0.018 mg QE/g).

The antioxidant activity of FDGP and SDGP samples was evaluated by DPPH and ABTS radical scavenging assays to assess the effect of ageing and extraction conditions. The mean DPPH scavenging ability of the SDGP (75.48 ± 0.04%) was higher than that of FDGP (75.00 ± 0.04%) ($p < 0.001$). The observed effect size (partial $\eta^2 = 0.913$) indicated a dominant effect, reflecting the substantial influence of ageing on the enhanced availability of antioxidant

compounds. With respect to extraction conditions, CW resulted in significantly higher antioxidant activity (76.74 ± 0.04%) as compared with HW (73.74 ± 0.04%) ($p < 0.001$). This factor showed a strong influence on the release of antioxidant compounds (partial $\eta^2 = 0.998$). The interaction between ageing and extraction solvent temperature was not significant ($p = 0.240$). Overall, the results indicated that SDGP CW (76.00 ± 0.05%) showed the highest antioxidant activity, while FDGP HW (73.47 ± 0.05%) showed the lowest. The data revealed that the mean ABTS scavenging activity of FDGP (76.74 ± 0.02 %) was slightly higher than that of SDGP (76.35 ± 0.02%) ($p < 0.001$). The large effect size (partial $\eta^2 = 0.945$) indicated pronounced effect of ageing on the antioxidant activity. In the case of the temperature of the extraction solvent, CW (78.43 ± 0.02%) performed better than the HW (74.66 ± 0.02%) ($p < 0.001$). The findings suggest that the antioxidant activity is significantly influenced by the temperature of the extraction solvent (partial $\eta^2 = 0.999$). The interaction between the storage period and temperature of extraction solvent was significant ($p < 0.001$; partial $\eta^2 = 0.985$). Although SDGP samples exhibited high DPPH scavenging activity, the ABTS showed a marginal higher value in FDGP, indicating that the effect of ageing on antioxidant activity is assay-dependent and may vary according to mechanism and sensitivity of assay. Overall, SDGP CW (78.62 ± 0.03%) and FDGP HW (74.09 ± 0.03%) showed the highest and lowest ABTS scavenging activity respectively, among the individual treatments. The observed antioxidant trend is consistent with phenolic and flavonoid content, indicating these phytochemicals play a major role in determining radical scavenging potential of samples. The results indicated that during the ageing process, the phenolic content of the *Garcinia pedunculata* slices was not adversely affected. Also, the TPC content of SDGP samples showed a marginal increase as compared to FDGP, partially supporting the traditional belief. It can be attributed to the structural softening of the matrix with ageing, which facilitates release of bound phenolic compounds from cell wall matrix [29].

Table 2. Total Phenolic Content (TPC), Total Flavonoid Content (TFC), and Antioxidant activity of Bor-thekera (*Garcinia pedunculata*) slices

Parameter	FDGP (CW)	FDGP (HW)	SDGP (CW)	SDGP (HW)
TPC (mg GAE/g DW)	6.23 ± 0.018	5.89 ± 0.004	6.30 ± 0.005	6.00 ± 0.007
TFC (mg QE/g DW)	3.16 ± 0.035	2.79 ± 0.02	3.02 ± 0.024	2.61 ± 0.035
DPPH (% RSA)	76.54 ± 0.156	73.46 ± 0.062	74.63 ± 0.137	72.75 ± 0.092
ABTS (% RSA)	78.24 ± 0.057	75.23 ± 0.029	76.89 ± 0.073	74.09 ± 0.024
Values are mean ± SD (n = 3). Differences were considered significant at $p < 0.05$				

3.3. FTIR

The FTIR spectra of fresh-dried (FDGP) and stored-dried (SDGP) *Garcinia pedunculata* revealed similar characteristic peaks, showing minimal variation between the two samples (Figure 2). The presence of key functional groups related to phenolic compounds, organic acids, and polysaccharides was observed. It indicated that no major significant alteration occurred in the primary functional groups during the ageing process. The band at around 3434 cm^{-1} corresponds to O–H stretching vibrations of hydroxyl groups, associated with phenolic compounds, polysaccharides, and hydrogen-bonded moisture [8]. The bands at 2926 cm^{-1} and 2853 cm^{-1} are associated with C–H stretching vibrations, and showed minimal variation between the two samples, indicating that the ageing process did not affect the

carbohydrate framework of the SDGP sample. The peak at 1732 cm^{-1} is characteristic of C=O stretching vibrations of esterified carboxyl groups, and the absorption band at 1634 cm-1 corresponds to symmetric COO^- stretching [8]. The band at 1065 cm^{-1} reflects the presence of C–O stretching vibrations and indicates the glycosidic linkages (C–O–C) and stretching of alcohol groups (C–O) in polysaccharides. The corresponding bands align with previous studies on FTIR analysis of *Garcinia pedunculata* and *Chenopodium album* [8,35]. Overall, the FTIR spectra of FDGP and SDGP were similar, and no major chemical shifts were observed. The minor variations in the band intensity may be attributed to minor structural modifications of ester-linked functional groups during the ageing process. These findings align with the observed phenolic content retention in the SDGP samples, supporting the inference that the functional integrity of dried Bor-thekera slices was maintained during the ageing process.

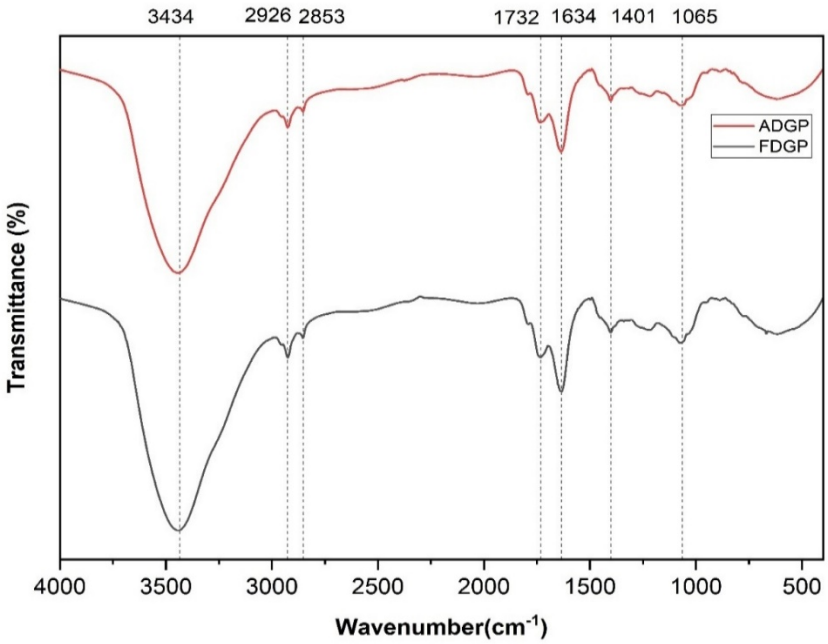

Figure 2. FTIR spectra of Stored-Dried (SDGP) and Fresh-Dried (FDGP) *Garcinia pedunculata*

3.4. Sensory Evaluation

The sensory evaluation of water infusions prepared from fresh-dried *Garcinia pedunculata* (FDGP) and stored-dried *Garcinia pedunculata* (SDGP) showed that the ageing process significantly influenced the sensory attributes (Figure 3). The water infusion prepared with SDGP slices received higher scores for color (7.30 ± 0.82) and taste (7.40 ± 0.69) in comparison to FDGP (6.60 ± 0.70 and 6.60 ± 0.52) ($p < 0.05$). Although the aroma scores of SDGP (7.50 ± 0.85) were higher than those of FDGP (6.90 ± 1.20), the differences were not statistically significant ($p > 0.05$). Similarly, the overall acceptability scores of both samples, SDGP (7.4 ± 0.69) and FDGP (7.2 ± 0.78), were statistically not significant ($p > 0.05$). The mouthfeel of both the samples, FDGP (7.0 ± 0.66) and SDGP (7.1 ± 0.87), indicated that the textural perception was not altered during the storage period. The sensory analysis scores revealed that the ageing process enhances the taste and color of water infusions, and the other parameters were not adversely affected. It aligns with the indigenous knowledge and supports the traditional belief that dried *Garcinia pedunculata* slices (Bor-thekera), when stored for a prolonged period, maintain the stability of their constituents. However, as the sensory

evaluation was carried out with a limited panel size for assessment of consumer acceptability, the small panel size may not fully represent wider consumer preferences. Therefore, future studies involving larger and trained sensory personnel may help in a comprehensive evaluation of the sensory preferences for product development.

Table 3. Sensory evaluation of FDGP and SDGP *Garcinia pedunculata* infused water using 9-point hedonic scale

Attribute	FDGP	SDGP
Colour	6.6 ± 0.69^{b}	7.3 ± 0.82^{a}
Aroma	6.9 ± 1.19^{a}	7.5 ± 0.84^{a}
Taste	6.6 ± 0.51^{b}	7.2 ± 0.78^{a}
Mouthfeel	7.0 ± 0.66^{a}	7.1 ± 0.87^{a}
Overall acceptability	7.2 ± 0.78^{a}	7.4 ± 0.69^{a}

- *Sensory scores were based on 9-point hedonic scale (1 = dislike extremely; 9 = like extremely)*
- *Values (mean ± SD) within a row displaying different superscripts differ significantly according to paired sample t-test ($p < 0.05$)*

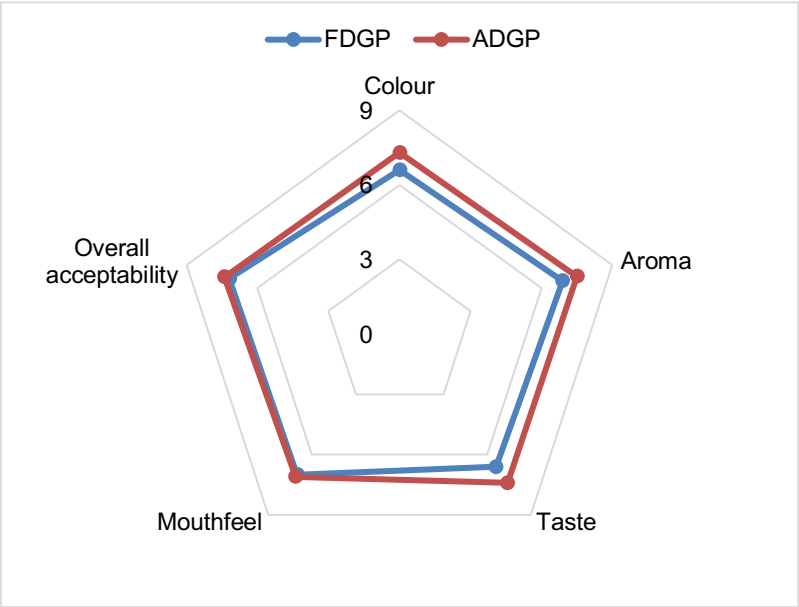

Figure 3. Radar plot showing the sensory attributes of Fresh-Dried (FDGP) and Stored-Dried *Garcinia pedunculata* (SDGP) slices water infusions

4. Conclusions

This study provides partial scientific support for the long-held belief about the ageing of Bor-thekera and its usage for culinary and ethnomedicinal purposes, particularly in terms of phenolic stability. The comparative analysis of FDGP (fresh-dried) and SDGP (four years aged) revealed that the structural and phytochemical integrity of slices was not significantly lost during the storage period. A marginal increase in the total phenolic content supported the hypothesis and traditional claims regarding the ageing practice. During the ageing process, some gradual physicochemical changes may contribute to enhancing the quality of the slices. The total flavonoid content of SDGP samples, though, showed a marginal reduction. In the case of physicochemical parameters, a decrease in pH and an increase in titratable acidity were observed. The antioxidant potential of SDGP was comparable to that of FDGP. Ageing led to darkening of the slices and reduced hydration-related properties. The sensory evaluation

revealed good overall acceptability of the stored dried samples. Thus, this study suggests the potential of stored-dried *Garcinia pedunculata* as a stable food ingredient based on its phenolic content and antioxidant profile, while highlighting the significance of sustainable indigenous preservation methods. However, the study is limited by comparison of two time points, which does not allow for interpretation of ageing kinetics. Inclusion of intermediate storage duration in future studies will enable a comprehensive understanding of physicochemical and phytochemical changes during the storage period. Furthermore, studies on bioavailability, bioaccessibility, and clinical validation are needed for functional efficacy. Future research on controlled ageing, in-depth advanced phytochemical profiling, may help to understand the physicochemical changes involved in enhancing or maintaining the quality of dried Bor-thekera without the addition of any preservatives.

Multidisciplinary Domains

This research covers the domains: (a) ethnobotany and traditional knowledge, and (b) food chemistry and functional food science.

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration on AI Usage

The authors declare that the manuscript has been prepared without the usage of AI tools.

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