

Sustainable Food Technology

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Sustainability Spotlight Statement

This study presents a sustainable approach to extending the shelf life of ready-to-drink fruit-based beverages by combining high-temperature short-time (HTST) pasteurization with amber-colored glass packaging. This method effectively preserves bioactive compounds, including phenolics and carotenoids, and maintains antioxidant activity, while ensuring microbial safety during storage. HTST pasteurization has been shown to require approximately 30% less energy than low-temperature long-time (LTLT) methods due to shorter processing times and rapid heat transfer, contributing to improved energy efficiency in food processing operations (Stoforos, 2016). By extending shelf life, this approach reduces food spoilage and waste, which can account for 20–30% of post-production losses in fruit-based beverages (FAO, 2019), thereby supporting more efficient resource utilization. Amber glass packaging further enhances sustainability: it is highly recyclable with material recovery rates exceeding 90% in well-established glass recycling systems (Ahlstrand, 2025), and its durability reduces dependence on single-use PET plastics. Life cycle assessment studies indicate that PET bottles typically generate 70–85% higher greenhouse gas emissions per functional unit compared to reusable glass packaging systems when reuse rates are adequately high (Issifu & Sumaila, 2025). Overall, this strategy promotes both product quality and environmental sustainability in the beverage industry by combining energy-efficient processing, waste minimization, and environmentally responsible packaging.



1 **Sustainable Shelf-Life Extension of Date Palm–Bael–Jujube Beverages through HTST**
2 **Pasteurization and Protective Packaging**

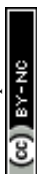
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19 Abstract

20 The impacts of packaging (transparent glass bottle vs amber-colored glass bottle) and
21 pasteurization (LTLT vs HTST) as a viable option of preserving Ready-to-Drink beverages made
22 from date palm extract mixed with bael fruit and jujube (date palm extract 70%: bael fruit juice
23 15%: jujube juice 15%) were investigated in this study. Physical-chemical properties and
24 microbiological counts were also investigated during storage at 4°C. Pasteurization and packaging
25 type significantly affected the preservation of bioactives and antioxidant activity of products
26 during cold storage ($p < 0.05$). At the end of the storage period (9 weeks), the HTST-pasteurized
27 samples in amber-colored glass bottles exhibited the highest total phenolic compound (586.33 mg
28 GAE/100 mL), total carotenoid content (3.25 mg β -CE/100 mL), and antioxidant activity (DPPH:
29 763.54 mM Trolox/100 mL; FRAP: 786.21 mM Trolox/100 mL). During storage, total soluble
30 solids (ranging from 6.6 to 7.2 °Brix) showed no significant changes ($p > 0.05$). HTST
31 pasteurization caused the least color change (ΔE) in amber-colored glass bottles during storage.
32 No microbial, yeast, or mold counts were detected in HTST-pasteurized samples stored in amber-
33 colored glass bottles until the 6th and 7th weeks of storage, respectively. Based on maximum
34 antioxidant activity retention and microbiological safety, the shelf life of HTST-pasteurized
35 samples in amber-colored glass bottles was calculated at 7 weeks. Finally, the use of HTST
36 pasteurization together with amber-colored glass packaging may represent a practical approach to
37 improving the preservation of ready-to-drink beverages.

38 **Keywords:** Date palm, functional drink, packaging, cold storage, thermal processing.

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40



41 1. Introduction

42 The date palm (*Phoenix dactylifera* L.) is a Middle Eastern native that thrives in dry regions. It
43 contains carbohydrates, dietary fiber, vitamins (C, B1, B2, A), and minerals including calcium,
44 iron, potassium, and zinc. Date palm phytochemicals are categorized into three categories:
45 phenolic, carotenoid, and tannins ¹. Instead of using compression methods, enzymatic extraction
46 using pectinase causes the fruit's characteristics to deteriorate and increases the release of bioactive
47 substances such as pigments and antioxidants from plant tissues ².

48 Researchers have expected the growth of unique beverage recipes as consumption preferences
49 have switched to the selection of healthy and helpful beverages. A drink made from date palm
50 extract, bael fruit, and jujube, all of which are high in antioxidants and vitamins, is a viable
51 example ^{3, 4}. However, even when refrigerated at 4°C, these beverages have a short shelf life of
52 about 2 weeks.

53 As a result, it is vital to utilize a preservation method that can increase the product's shelf life.

54 Pasteurization in combination with consumer-friendly packaging that preserves the quality of
55 ready-to-drink (RTD) beverage goods is a viable alternative. The packaging of a product has a
56 significant impact on its shelf life ^{5, 6}. Choosing the correct packaging in combination with
57 pasteurization not only extends the shelf life of the food, but also protects it against moisture,
58 microbiological contamination, light, air, and different gases during handling, shipping, and
59 storage ^{7, 8}.

60 Despite the importance of both thermal processing and packaging in sustainable beverage
61 preservation, limited research has investigated complementary effects of pasteurization and



62 protective packaging on the quality and stability of RTD functional beverages, particularly those
63 containing multiple fruit sources.

64 Therefore, this study evaluated the influence of pasteurization conditions (low-temperature long-
65 time (LTLT) and high-temperature short-time (HTST)) and glass bottle color (transparent vs.
66 amber) on the physicochemical characteristics, bioactive retention, antioxidant activity, and
67 microbiological quality of a date palm-based RTD beverage mixed with bael fruit and jujube
68 during refrigerated storage. The findings are expected to provide insights into energy-efficient and
69 sustainable preservation strategies for functional beverages with extended shelf life.

70 2. Materials and methods

71 2.1. Sample preparation

72 The fresh date palms (Bahi variety) at rutab stage were supplied from Kanchanaburi province in
73 Thailand. Dried bael fruit and jujube were also obtained from Yaowarat Old Market in Bangkok,
74 Thailand. All samples were delivered to Department of Food Technology in Chulalongkorn
75 University. The date palms were dried in a hot air oven (Memmert, DO 6062, Germany) at 60°C
76 for 48 hours until moisture content was reduced to <10%, then vacuum-packed in aluminum-
77 laminated foil bags, and kept at -20°C for subsequent use.

78 For date palm juice extraction, dried date palms were rehydrated in distilled water at a ratio of 1:3
79 (w/v) and subjected to enzymatic treatment with 0.1% pectinase (Sigma-Aldrich, USA) at 45°C
80 for 2 hours to enhance juice yield and bioactive compound extraction. The mixture was then
81 filtered through cheesecloth to obtain the juice. Date palm concentrate (33.33% w/v) was prepared
82 by dissolving the concentrated extract in distilled water to achieve the desired concentration.



83 Bael fruit juice and jujube juice were obtained separately by boiling dried bael fruit and dried
84 jujube, respectively, in distilled water at a ratio of 1:10 (w/v) for 5 minutes, followed by filtration
85 through cheesecloth. The final ready-to-drink beverage was formulated by mixing date palm
86 extract (70% v/v), bael fruit juice (15% v/v), and jujube juice (15% v/v).

87 **2.2. Preparation of ready-to-drink beverage from date palm extract**

88 Based on our prior experiment, the optimum extraction condition as well as the best ready-to-drink
89 beverage from date palm extract were used (data not shown). The best ready-to-drink was; date
90 palm juice extract (70% v/v): Bael fruit juice (15% v/v) with jujube juice (15% v/v). Date palm
91 juice was prepared from date palm concentrate at a concentration of 33.33% (w/v), while Bael fruit
92 juice and jujube juice were obtained by boiling dried Bael fruit and dried jujube, respectively, for
93 5 min at the ratio of fruit to water of 10% (w/v).

94 **2.3. Thermal processing and packaging of ready-to-drink beverage from date palm extract** 95 **during the storage at 4°C**

96 The thermal treatments were applied according to established pasteurization protocols. For HTST
97 pasteurization, the beverage samples were rapidly heated to 72°C and held at this temperature for
98 20 seconds using a steam-jacketed pasteurizer to ensure uniform heat distribution, as described by
99 ⁹. For LTLT pasteurization, the samples were gradually heated to 63°C and maintained at this
100 temperature for 30 minutes in a thermostatically controlled water bath. Following heat treatment,
101 the samples were immediately subjected to rapid cooling in an ice bath to quickly reduce the
102 temperature to 4°C within 5 minutes, thereby preventing overprocessing and preserving bioactive
103 compounds. Both HTST and LTLT-treated beverages were aseptically filled into pre-sterilized
104 (autoclaved at 121°C for 15 min) transparent and amber-colored glass bottles (250 mL capacity)



105 and sealed immediately with sterilized screw caps under a laminar flow hood to minimize post-
106 process contamination. As a control, unpasteurized samples were handled under the same aseptic
107 conditions without thermal treatment. All samples were stored at 4°C for up to 9 weeks, with
108 weekly assessments of physicochemical parameters to monitor product quality and safety during
109 storage.

110 **2.4. Determination of Physical and Chemical properties of ready-to-drink beverage from** 111 **date palm extract during the storage at 4°C**

112 Color was determined by Chroma meter (Monica Minolta CR-400, Japan), CIE color system and
113 L*, a* and b* values were adjusted by the machine before every sample measurement. L*
114 represents a lightness value ranging from 0 (dark) to 100 (white), a* represents redness (+a*) and
115 greenness (-a*) and b* represents yellowness (+b*) and blueness (-b*). Color difference (ΔE^*)
116 was measured by the following equation:

$$117 \Delta E^* = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$$

118 Where, subscript 1 is the initial color values and subscript 2 is the color value measured at a time
119 of the sample.

120 Total soluble solid content (°Brix) was measured by digital refractometer (HI96801, Hanna, USA)
121 at 0-85 °Brix. The pH was measured by pH meter (Mettler toledo, Switzerland). The determination
122 of total acid content (% citric acid) was conducted by titration method according to ¹⁰.

123 Total phenolic compound content (TPC) was determined by Folin-Ciocalteu as described by ¹¹
124 with some modifications. In brief, sample (100 µL) was mixed with into distilled water (7 mL) and
125 Folin-Ciocalteu reagent (500 µL) and left at room temperature for 3-5 min. Then, sodium
126 carbonate (400 µL) was added to the solution and left for another 30 min in a dark place. The



127 absorption was measured with the UV–visible spectrophotometer (GENE-SYSTEM 20 Visible,
128 Thermo Fisher Scientific, USA) at a wavelength of 765 nm and the TPC was calculated using the
129 absorption obtained compared with the gallic acid solution standard curve and the results were
130 represented as mg gallic acid equivalent/liter (mg GAE/L).

131 Total carotenoid content was determined using a spectrophotometric method as described by ¹²,
132 with slight modifications. Briefly, an aliquot of the sample was extracted with an appropriate
133 solvent system (e.g., acetone: hexane, 4:6 v/v) and centrifuged at $5000 \times g$ for 10 min to remove
134 particulates. The clear supernatant was collected, and the absorbance was measured at 450 nm
135 using a UV–visible spectrophotometer (GENE-SYSTEM 20 Visible, Thermo Fisher Scientific,
136 USA). A standard curve was prepared using known concentrations of β -carotene dissolved in the
137 same solvent system. Total carotenoid content was calculated from the standard curve and
138 expressed as milligrams of β -carotene equivalents per 100 mL of sample (mg β -CE/100 mL)

139 The antioxidant activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH) method was as described
140 previously by ¹³. Sample (250 μ L) was mixed with DPPH solution (4.75 mL) and set in the dark
141 at room temperature for 15 min. The absorbance of the samples was measured at a wavelength of
142 515 nm using methanol as a blank. Then, subtract the absorption value of the DPPH solution
143 (A_{initial}) from the absorbance of the sample (A_{final}). The calculation of the DPPH was based on the
144 $A_{\text{difference}}$ values and the standard curve of Trolox and expressed as mM Trolox/100 mL.

145 The antioxidant activity by ferric reducing antioxidant power (FRAP) was as described by ¹⁴ with
146 slight modification. Sample (50 μ L) was mixed with FRAP solution (950 μ L) and left at room
147 temperature for 4 min. The absorbance of the sample at a wavelength of 593 nm, using distilled
148 water as the blank. The concentration of FRAP was determined by the absorbance difference of



149 the sample and the FRAP solution as well as the standard curve of Trolox and expressed as mM
150 Trolox/100 mL.

151 All analyses were performed in triplicate. Standard curves were prepared using gallic acid (0-100
152 mg/L, $R^2 > 0.99$) for TPC, β -carotene (0-10 $\mu\text{g/mL}$, $R^2 > 0.99$) for TCC, and Trolox (0-500 μM ,
153 $R^2 > 0.99$) for DPPH and FRAP assays. Method validation included recovery studies (95-105%)
154 and precision assessment ($\text{RSD} < 5\%$).

155 **2.5. Determination of total bacteria count and yeast and mold of ready-to-drink beverage** 156 **from date palm extract during the storage at 4°C**

157 For microbiological analyses, samples were aseptically transferred to sterile containers, and serial
158 dilutions were prepared using 0.1% peptone water. For total plate count, 1 mL of appropriate
159 dilutions was pipetted into sterile Petri dishes, followed by the addition of 15-20 mL of molten
160 Plate Count Agar (PCA; Merck, Germany) cooled to 45°C. The plates were gently swirled for
161 even distribution and allowed to solidify. After solidification, plates were incubated at $35 \pm 2^\circ\text{C}$
162 for 48 hours. For yeast and mold enumeration, 0.1 mL of appropriate dilutions was spread onto
163 the surface of pre-poured PDA (Merck, Germany) plates acidified with 10% tartaric acid to inhibit
164 bacterial growth. Plates were incubated at $25 \pm 2^\circ\text{C}$ for 3-5 days. Colonies were counted and results
165 expressed as log CFU/mL.

166 Coliform counts were determined according to the method described by ¹⁵ and expressed as the
167 most probable number per milliliter (MPN/mL) of sample. The three-tube MPN technique was
168 employed using Lauryl Tryptose Broth (LTB; Merck, Germany) for presumptive coliform
169 detection. For each dilution (10^0 , 10^{-1} , and 10^{-2}), three tubes containing 10 mL of LTB with
170 inverted Durham tubes were inoculated with 1 mL of the appropriate sample dilution. Tubes



171 showing gas production after incubation at $35 \pm 0.5^{\circ}\text{C}$ for 24-48 hours were considered
172 presumptive positive. Confirmatory tests were then performed by transferring a loopful from
173 positive LTB tubes into Brilliant Green Lactose Bile (BGLB) Broth (Merck, Germany) and
174 incubating at $35 \pm 0.5^{\circ}\text{C}$ for an additional 24-48 hours. Tubes exhibiting gas formation were
175 recorded as confirmed positive for coliforms, and the results were calculated using standard MPN
176 tables.

177 Shelf life was determined based on the earliest occurrence of either: (1) microbiological
178 exceedance of regulatory limits, or (2) significant reduction in antioxidant activity compromising
179 functional quality. According to the Ministry of Public Health, Thailand, the microbiological limits
180 for pasteurized fruit beverages are: total bacteria count $\leq 4 \log \text{CFU/mL}$, yeast and mold count \leq
181 $2 \log \text{CFU/mL}$, and coliforms $< 3 \text{MPN/mL}$. For antioxidant activity, a 50% reduction from initial
182 values was considered the threshold for significant quality loss, as this represents the point at which
183 the functional claim of the beverage would be compromised.

184 2.6. Statistical analysis

185 The experimental design followed a completely randomized design (CRD) with three replicates
186 per treatment. A two-factor analysis of variance (ANOVA) was employed to evaluate the effects
187 of pasteurization (control, LTLT, HTST) and packaging type (transparent glass vs. amber-colored
188 glass) during storage. Data were analyzed using the Statistical Package for the Social Sciences
189 (SPSS, Version 22.0; IBM Corp., Armonk, NY, USA). When significant differences were
190 observed among treatments ($p \leq 0.05$), mean comparisons were performed using Tukey's Honestly
191 Significant Difference (HSD) test at a 95% confidence level. All results are presented as mean \pm
192 standard deviation (SD).



193 3. Results and discussion

194 3.1. Effects of thermal processing and packaging on physicochemical properties of ready-to- 195 drink beverage from date palm extract during the storage at 4°C

196 During the 9 weeks of storage, the total acid content of samples, particularly control samples,
197 tended to increase (Table 1). Samples had an initial total acid level of 0.10 to 0.11 % citric acid
198 ($P>0.05$). At the end of the storage period, the total acid level of control samples in transparent
199 and amber-colored glass bottles was 0.38 and 0.39 %, respectively. At the end of storage (9 weeks),
200 the total acid level of pasteurized samples in transparent and amber-colored glass bottles ranged
201 from 0.11 to 0.13 %. Pasteurization had an impact on the product storage phase since it kills the
202 bacteria that cause food degradation while also preserving it ⁹.

203 Table 2 shows that the initial pH value ranged from 4.35 to 4.37, which was not significantly
204 different ($p>0.05$). Control samples in clear and amber-colored glass bottles had pH values of 3.81
205 and 3.82, respectively, which were lower than the other samples. Throughout the storage period,
206 there were no significant differences in total soluble solids ($p>0.05$). During storage, the total
207 amount of soluble solids in the samples tends to decrease slightly, which is consistent with the pH
208 value. Table 3 shows that total soluble solids ranged from 6.9 to 7.2 °Brix. These findings suggest
209 that total soluble solids are closely associated with total acid content and pH. The observed
210 decrease in pH is attributed to the accumulation of acids resulting from the metabolic activity of
211 lactic acid bacteria, which utilize sugars for growth and fermentation, consequently reducing the
212 total soluble solids ¹⁶.

213 In terms of color values, the L* and b* values showed decreasing trends during the storage. The
214 L* value was 52.14 to 58.61, while the b* value was 67.52 to 70.59. (Table 4). Carotenoids are
215 phytochemicals that are sensitive to oxygen, heat, and other environmental factors. As a result of



216 the reaction of polyphenol oxidase (PPO) or browning process associated to this enzyme, the b^*
217 value that shows yellowness is lowered during storage, while the a^* value that indicates redness is
218 increased. As shown in our results, pasteurized samples (HTST) contained in amber-colored glass
219 bottle had less color change, resulting in samples having less color changes than samples from the
220 LTLT. The color change (ΔE^*) in HTST samples contained in clear and amber-colored glass
221 bottles ranged from 1.16 to 6.66 and 0.65 to 4.81, respectively. However, the color change (ΔE^*)
222 among LTLT samples in clear and amber-colored glass bottles ranged respectively from 2.90 to
223 8.57 and 0.62 to 5.71 during the storage. Amber-colored glass bottles provide superior protection
224 against light-induced degradation of ready-to-drink beverages, such as date palm extract, by
225 effectively blocking ultraviolet (UV) and visible light wavelengths below 450 nm. This shielding
226 prevents photooxidation, thereby preserving the color, antioxidant activity, and overall quality of
227 the product ¹⁷.

228 **3.2. Effects of thermal processing and packaging on bioactive compounds and antioxidant** 229 **activity properties of ready-to-drink beverage from date palm extract during the storage** 230 **at 4°C**

231 Throughout the storage period, the total amount of phenolic compounds (TPC) in all samples
232 decreased, which could be due to oxidation and non-enzymatic reactions, which can be accelerated
233 by factors like oxygen exposure, light, and prolonged storage. TPC was reduced by 49.87 percent
234 over the same period from its starting value in the samples. This was in line with the findings of ¹⁸
235 who investigated the storage quality of non-thermally pasteurized and microfiltered pineapple
236 juice at various temperatures (4, 27, and 37 °C). The results indicated that TPC of the juice
237 significantly decreased as storage time and temperature increased ($p \leq 0.05$), with the highest
238 retention observed at 4 °C. This suggests that lower storage temperatures help preserve the



239 phytochemical properties of the juice. Our findings also revealed that ready-to-drink date palm
240 juice (HTST) packed in amber-colored glass bottles could maintain the highest level of TPC during
241 storage. In line with our results, ¹⁹ demonstrated blueberry extract preserved in glass bottles at
242 different temperatures (-20, 6, 23 and 35 °C) for 60 days showed a mild decrease in the TPC value
243 especially at -20°C (Table 5).

244 The degradation of phenolic compounds during storage can be attributed to multiple mechanisms,
245 including enzymatic oxidation by polyphenol oxidase (PPO), non-enzymatic oxidation, and
246 polymerization reactions. PPO catalyzes the oxidation of phenolic compounds to quinones, which
247 subsequently polymerize to form brown pigments, leading to both color changes and reduced
248 antioxidant capacity ²⁰. The higher retention of TPC in HTST-treated samples compared to LTLT-
249 treated samples can be explained by the rapid inactivation of PPO during HTST processing, as the
250 short exposure time at high temperature effectively denatures enzymes while minimizing thermal
251 degradation of heat-sensitive phenolic compounds ²¹.

252 Carotenoids are naturally occurring pigments found in various fruits and vegetables, imparting red,
253 orange, yellow, and green hues. These compounds are not only responsible for the vibrant colors
254 of many plant-based foods but also offer significant health benefits. Among them, β -carotene is
255 the most prevalent provitamin A carotenoid, which the human body can convert into vitamin A,
256 essential for vision, immune function, and skin health ²². It was found that the total β -carotene
257 content (TCC) values of the samples tended in the same direction as TPC did during the storage.
258 However, pasteurized (HTST) samples-packaged in amber-colored glass bottles contained a higher
259 TCC value (3.25 mg β -CE/100 mL) at the end of the storage (Table 5). The average reduction of
260 TCC was approximately 54.74% from the initial value. The study by ²³ investigated the effects of
261 refrigerated storage on the stability of bioactive compounds in orange juice. The researchers



262 observed that after 40 days of storage at 4 °C, TCC of pasteurized orange juice decreased by
263 16.90%. This finding underscores the impact of storage conditions on the retention of carotenoids
264 in fruit juices, highlighting the need for optimized preservation methods to maintain their
265 nutritional quality ²³. In the context of ready-to-drink beverages derived from date palm extract,
266 TCC plays a crucial role in determining the nutritional value and overall quality of the product.

267 Carotenoid degradation occurs primarily through photo-oxidation and auto-oxidation mechanisms.
268 Carotenoids are highly susceptible to isomerization and oxidation when exposed to light,
269 particularly UV radiation, which generates singlet oxygen and free radicals that attack the
270 conjugated double-bond system ²². Amber-colored glass bottles provide protection by filtering
271 light wavelengths below 450 nm, including UV and blue light, which are most damaging to
272 carotenoids. This explains the significantly higher TCC retention (3.25 mg β -CE/100 mL) in amber
273 glass-packaged samples compared to transparent glass-packaged samples (0.54 mg β -CE/100 mL)
274 at week 9. The reduction pattern of bioactive compounds observed in our study is consistent with
275 findings from other fruit beverage studies. ²³ reported a 16.9% decrease in total carotenoid content
276 of pasteurized orange juice after 40 days of storage at 4°C, while we observed a 54.7% reduction
277 over 63 days, which is comparable when normalized to time (approximately 0.42% per day vs.
278 0.87% per day). The higher degradation rate in our product may be attributed to the presence of
279 multiple fruit sources with different carotenoid profiles and potentially different stability
280 characteristics.

281 ¹⁸ found that pineapple juice stored at 4°C retained significantly higher TPC compared to storage
282 at 27°C or 37°C, emphasizing the critical role of refrigeration in preserving bioactive compounds.
283 Our results extend these findings by demonstrating that packaging light protection provides an
284 additional preservation benefit beyond temperature control alone.



285 It was found that the antioxidant effects of DPPH and FRAP of all samples tended to decrease
286 throughout the cold storage period. The initial DPPH and FRAP values of the samples ranged
287 respectively from 1421.88 to 1448.96 mM trolox/100 mL and 1419.55 to 1430.26 mM trolox/100
288 mL and reached to 638.54 and 588.60 for DPPH and FRAP, respectively. The DPPH and FRAP
289 decrease during the storage were 46.85% and 44.94% from the initial antioxidant effect,
290 respectively (Table 5). The highest DPPH and FRAP values were found in pasteurization (HTST)
291 samples maintained in amber-colored glass bottles, with values of 763.54 and 786.21 mM
292 trolox/100 mL, respectively (Table 5).

293 ²⁴ reported that thermal processing of mango juice led to an increase in antioxidant activity
294 compared to untreated control samples. This enhancement is likely associated with the inactivation
295 of polyphenol oxidase (PPO), an enzyme responsible for catalyzing the oxidation of polyphenolic
296 compounds. By inhibiting PPO activity, thermal treatment reduces the degradation of phenolic
297 compounds, thereby preserving or even enhancing the antioxidant capacity of the juice. Similar
298 mechanisms may explain the observations in the present study, where controlled heat processing
299 contributed to the retention of bioactive compounds and the improvement of antioxidant properties
300 in the ready-to-drink beverage from date palm juice. ²⁵ also discovered that the type of packaging
301 could impact the number of antioxidants and their effects during preservation.

302

303 **3.3. Effects of thermal processing and packaging on microbiological quality of ready-to-** 304 **drink beverage from date palm extract during the storage at 4°C**

305 Thermal processing is a widely employed method in food preservation that utilizes heat to destroy
306 harmful microorganisms and inactivate enzymes responsible for food spoilage. This technique



307 extends the shelf life of food products, ensuring safety and quality during storage and distribution

308 ²⁶.

309 Packaging plays a crucial role in maintaining the quality and extending the shelf life of food
310 products. The choice of packaging material affects factors such as oxygen permeability, moisture
311 resistance, and protection from light and contaminants. Glass bottles are particularly effective in
312 preserving food quality due to their excellent gas and moisture barrier properties, as well as their
313 inertness to chemical and biological interactions ⁸.

314 Incorporating both thermal processing and appropriate packaging materials can significantly
315 enhance food preservation, benefiting both consumers and businesses by ensuring food safety and
316 reducing waste.

317 The most prevalent and crucial aspect in food goods is the degradation process produced by
318 microbes, as it directly impacts the shelf life of food and is an indicator of consumer safety. As a
319 result, the number of microorganisms in food products should not be excessive. Food deterioration
320 induced by microorganisms is caused by the growth and rise in the quantity of microbes, which
321 causes food to change in various ways, including strange odors and color changes. Therefore,
322 microbial spoilage is often found in fresh foods such as vegetables, fruits, fresh milk and meat,
323 and spoilage is caused by three main types of microorganisms: bacteria, yeast and mold ²⁷⁻²⁹.

324 The total microbial count of control samples in both amber-colored and clear glass bottles was
325 found to be higher than that of pasteurized (LTLT and HTST) samples. Until 5 weeks after storage,
326 all pasteurized (LTLT and HTST) samples revealed no signs of bacterial contamination (Table 6).
327 At the end of storage, the total microbial content in the control group grew from 1.39 to 7.06 log



328 CFU/mL. According to a statement from the Ministry of Public Health, total microbial content in
329 foods must not exceed 4 log CFU/mL, which was the case for our pasteurization samples.

330 Yeast and mold content in control samples stored in amber and transparent glass bottles rose from
331 2.40 to 5.16 and 6.04 log CFU/mL, respectively, during storage. Pasteurized (LTLT) samples
332 packed in transparent glass bottles started growing yeast and mold in Week 6 (1.00 log CFU/mL),
333 while pasteurized (LTLT and HTST) samples packed in amber glass bottles started growing yeast
334 and mold in Week 7 (1.15 log CFU/mL) (Table 6). The observation that amber-colored glass
335 bottles delayed microbial growth compared to transparent glass bottles can be explained by the
336 light-filtering properties of amber glass. Amber glass effectively blocks ultraviolet (UV) and
337 visible light wavelengths below 450 nm, which are known to promote microbial growth through
338 several mechanisms. First, light exposure can increase the temperature of the product through
339 radiative heating, creating more favorable conditions for microbial proliferation. Second, photo-
340 oxidation reactions generate reactive oxygen species that can stress and potentially weaken
341 microbial cells, but paradoxically, some microorganisms may adapt and become more resilient¹⁷.

342 Third, light-induced degradation of antimicrobial compounds naturally present in the beverage
343 (such as phenolic compounds) may reduce the product's intrinsic antimicrobial activity over time.

344 The delayed onset of yeast and mold growth in amber glass-packaged samples (week 7) compared
345 to transparent glass-packaged samples (week 6) suggests that light protection helps maintain the
346 beverage's natural antimicrobial barriers for a longer period. This finding aligns with³⁰, who
347 reported that light-protective packaging significantly reduced fungal spoilage in fresh produce.

348 Pasteurization is an effective method for reducing microbial contamination in fruit juices. For
349 instance, the Ministry of Public Health, stipulates that yeast and mold counts in fruit juices should
350 not exceed 2 log CFU/mL. In line with this, a study by³¹ demonstrated that pasteurization of



351 *Passiflora setacea* pulp led to a significant reduction in yeast and mold counts, achieving levels
352 below the recommended threshold. Similarly, ³² observed that pasteurized pomegranate juice
353 stored at both 5°C and 25°C exhibited lower microbial growth compared to unpasteurized controls,
354 highlighting the efficacy of pasteurization in enhancing the microbiological safety of fruit juices
355 during storage. These findings underscore the importance of pasteurization in ensuring the
356 microbiological quality of fruit juices, aligning with both regulatory standards and scientific
357 evidence.

358 During storage, coliforms were not detected in any of the samples (Table 6), indicating that the
359 production processes were conducted under hygienic and appropriate conditions ³³. This finding
360 highlights the effectiveness of good manufacturing practices in ensuring microbiological safety.
361 Moreover, extending the shelf life of food products requires careful consideration of packaging
362 selection, as packaging is a critical factor in controlling the growth of bacteria, yeast, and mold
363 during storage. Proper packaging can create barriers against microbial contamination, oxygen, and
364 moisture, thereby maintaining product quality and safety over time. Compared to pomegranate
365 juice studies ³², which showed microbial stability for 4-5 weeks at 5°C, our combination of HTST
366 pasteurization and amber glass packaging extended microbial stability to 7 weeks, representing a
367 40-75% improvement.

368 Based on yeast and mold counts and measurements of antioxidant activity, the ready-to-drink
369 beverage prepared from date palm extract and subjected to HTST pasteurization, when stored in
370 amber-colored glass bottles, exhibited the longest shelf life of seven weeks at 4°C. Applying these
371 criteria, yeast and mold counts in HTST-pasteurized samples in amber glass remained below 2 log
372 CFU/mL until week 7 (1.00 log CFU/mL at week 7), exceeding the limit only at week 8, while
373 antioxidant activity (DPPH) decreased by 46.85% from initial values by week 9, approaching but



374 not exceeding the 50% threshold until that time. Therefore, week 7 represents the conservative
375 shelf-life endpoint based on the most limiting factor (yeast and mold count). This condition
376 outperformed other treatment combinations, with control samples exceeding microbiological
377 limits by week 3, indicating that the combination of HTST pasteurization and amber glass
378 packaging extended shelf life by approximately four weeks. These results highlight the
379 effectiveness of integrating optimized thermal treatment and protective packaging to preserve both
380 microbiological quality and bioactive properties, maximizing shelf life and functional quality in
381 fruit-based beverages.

382 While the present study demonstrates the efficacy of thermal pasteurization and protective
383 packaging, it is important to acknowledge that alternative non-thermal preservation technologies
384 are emerging as potentially more energy-efficient options for beverage preservation. UV treatment,
385 particularly in the germicidal wavelength range of 254-280 nm, has shown promise for inactivating
386 microorganisms in fruit juices without the thermal degradation associated with pasteurization ³⁴.
387 Studies on UV-treated apple juice and orange juice have demonstrated significant microbial
388 reduction while maintaining higher levels of heat-sensitive bioactive compounds compared to
389 thermal pasteurization ³⁵. However, UV treatment efficacy can be limited by juice turbidity and
390 color, which reduce light penetration—a challenge that may be relevant for the dark-colored date
391 palm beverage in our study.

392 Other non-thermal technologies including high-pressure processing (HPP), pulsed electric fields
393 (PEF), and cold plasma have also been investigated for fruit juice preservation. These technologies
394 offer the advantage of reduced energy consumption and better retention of fresh-like qualities, but
395 require higher capital investment and may have regulatory approval limitations in some regions ³⁶.



396 Aseptic packaging with improved surface disinfection represents another sustainable approach,
397 combining sterile filling with advanced packaging materials that incorporate oxygen scavengers
398 or antimicrobial compounds³⁷. Future research could explore combinations of mild thermal
399 treatment with these emerging technologies to further optimize the sustainability-performance
400 balance for date palm-based beverages.

401 **4. Conclusions**

402 This study demonstrated that both pasteurization method and packaging type significantly
403 influenced the physicochemical properties, antioxidant activity, and microbial stability of ready-
404 to-drink beverages formulated from date palm extract, quince juice, and jujube juice during storage
405 at 4°C. HTST pasteurization combined with amber-colored glass bottles effectively preserved
406 bioactive compounds, including total phenolic content (586.33 mg GAE/100 mL), total carotenoid
407 content (3.25 mg β -CE/100 mL), and antioxidant activities (DPPH: 763.54 mM trolox/100 mL;
408 FRAP: 786.21 mM trolox/100 mL), while maintaining microbial safety throughout storage. The
409 use of durable, reusable, amber-colored glass bottles, coupled with efficient HTST pasteurization,
410 not only extended shelf life to seven weeks but also supports sustainability by reducing reliance
411 on single-use packaging and minimizing food waste. Overall, these results indicate that the
412 application of optimized thermal processing alongside sustainable packaging practices may
413 contribute to maintaining product quality while supporting environmentally responsible
414 production of ready-to-drink fruit-based beverages.

415 **Data availability**

416 The data in the current study are available from the corresponding author upon reasonable request.

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424 **Authors Contribution**

425 Pitchaya Tuntiteeraboon: Investigation, Formal analysis, Data curation and Writing – original draft.
426 Sochannet Chheng: Data curation and Writing – original draft. Saeid Jafari: Data curation and
427 Writing – original draft. Isaya Kijpatanasilp: Data curation and Writing – original draft. Kitipong
428 Assatarakul: Conceptualization, Data curation, Funding acquisition, Project administration,
429 Supervision, Writing – original draft and Writing – review & editing.

430 **Conflict of Interest**

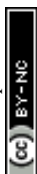
431 The authors declare no conflicts of interest, financial or personal, that could have influenced the
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Sustainable Food Technology Accepted Manuscript

500 **Table 1.** Effects of packaging and pasteurization on total acid content of Ready-to-Drink
 501 beverages from date palm extract during Storage at 4°C

| Storage (week) | Treatments | | | | | |
|-------------------|---------------------------|-------------------------|------------------------|-----------------------------|-------------------------|-------------------------|
| | Transparent glass bottles | | | Amber-colored glass bottles | | |
| | Control | LTLT | HTST | Control | LTLT | HTST |
| 0 ^{ns} | 0.11±0.01 | 0.10±0.01 | 0.10±0.01 | 0.11±0.01 | 0.10±0.01 | 0.10±0.01 |
| 1 | 0.11±0.01 ^a | 0.10±0.01 | 0.12±0.01 ^a | 0.09±0.01 ^b | 0.10±0.01 | 0.11±0.01 ^a |
| 2 | 0.18±0.01 ^a | 0.11±0.01 ^b | 0.11±0.01 ^b | 0.18±0.01 ^a | 0.11±0.01 ^b | 0.11±0.01 ^b |
| 3 | 0.27±0.01 ^a | 0.10±0.01 ^d | 0.13±0.01 ^c | 0.20±0.01 ^b | 0.10±0.01 ^d | 0.13±0.01 ^c |
| 4 | 0.34±0.01 ^a | 0.11±0.01 ^c | 0.12±0.01 ^c | 0.25±0.01 ^b | 0.11±0.01 ^c | 0.12±0.01 ^c |
| 5 | 0.32±0.01 ^a | 0.12±0.01 ^{de} | 0.14±0.01 ^c | 0.26±0.01 ^b | 0.11±0.01 ^e | 0.13±0.01 ^{cd} |
| 6 | 0.39±0.01 ^a | 0.10±0.01 ^d | 0.13±0.02 ^c | 0.31±0.01 ^b | 0.11±0.01 ^{cd} | 0.11±0.01 ^{cd} |
| 7 | 0.36±0.01 ^a | 0.11±0.01 ^c | 0.11±0.01 ^c | 0.30±0.01 ^b | 0.10±0.01 ^c | 0.12±0.01 ^c |
| 8 | 0.37±0.01 ^a | 0.10±0.01 ^c | 0.14±0.01 ^b | 0.36±0.01 ^a | 0.08±0.01 ^d | 0.11±0.01 ^c |
| 9 | 0.38±0.01 ^a | 0.12±0.03 ^b | 0.13±0.01 ^b | 0.39±0.01 ^a | 0.11±0.01 ^b | 0.13±0.01 ^b |

502 High temperature-short time (HTST, temperature 72°C, 20 sec),

503 Low temperature-long time (LTLT, temperature 63°C, 30 min)

504 “ns” indicates no significantly ($p>0.05$) different in each row.

505 Control: (date palm extract (70%): Bael fruit juice (15%): Jujube juice (15%)).

506 **Table 2.** Effects of packaging and pasteurization on pH value of Ready-to-Drink beverages from date palm extract during Storage at
 507 4°C

| Storage (week) | Treatments | | | | | |
|-------------------|---------------------------|------------------------|------------------------|-----------------------------|------------------------|------------------------|
| | Transparent glass bottles | | | Amber-colored glass bottles | | |
| | Control | LTLT | HTST | Control | LTLT | HTST |
| 0 ^{ns} | 4.37±0.01 | 4.35±0.01 | 4.36±0.01 | 4.37±0.01 | 4.35±0.01 | 4.36±0.01 |
| 1 | 4.27±0.02 ^b | 4.35±0.01 ^a | 4.36±0.02 ^a | 4.26±0.02 ^b | 4.35±0.01 ^a | 4.36±0.02 ^a |
| 2 | 3.87±0.02 ^b | 4.38±0.01 ^a | 4.36±0.01 ^a | 3.96±0.01 ^b | 4.35±0.01 ^a | 4.36±0.01 ^a |
| 3 | 3.85±0.01 ^b | 4.32±0.01 ^a | 4.35±0.01 ^a | 3.86±0.02 ^b | 4.35±0.02 ^a | 4.35±0.01 ^a |
| 4 | 3.84±0.01 ^b | 4.32±0.02 ^a | 4.35±0.02 ^a | 3.86±0.02 ^b | 4.36±0.02 ^a | 4.35±0.01 ^a |
| 5 | 3.83±0.01 ^b | 4.32±0.02 ^a | 4.35±0.01 ^a | 3.84±0.02 ^b | 4.36±0.04 ^a | 4.35±0.03 ^a |
| 6 | 3.80±0.01 ^b | 4.32±0.01 ^a | 4.32±0.04 ^a | 3.84±0.03 ^b | 4.36±0.04 ^a | 4.35±0.03 ^a |
| 7 | 3.81±0.02 ^b | 4.30±0.02 ^a | 4.32±0.01 ^a | 3.83±0.02 ^b | 4.34±0.03 ^a | 4.35±0.01 ^a |
| 8 | 3.80±0.01 ^b | 4.30±0.08 ^a | 4.31±0.03 ^a | 3.83±0.05 ^b | 4.34±0.02 ^a | 4.34±0.05 ^a |
| 9 | 3.81±0.03 ^b | 4.30±0.02 ^a | 4.31±0.01 ^a | 3.82±0.05 ^b | 4.32±0.03 ^a | 4.34±0.01 ^a |

508 High temperature-short time (HTST, temperature 72°C, 20 sec),
 509 Low temperature-long time (LTLT, temperature 63°C, 30 min)
 510 “ns” indicates no significantly (p>0.05) different in each row.
 511 Control: (date palm extract (70%): Bael fruit juice (15%): Jujube juice (15%)).
 512 Data are presented as mean ± Standard Deviation
 513 Different letters (a-b) refer to the significant differences (p≤0.05) in each row.

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519 **Table 3.** Effects of packaging and pasteurization on total soluble solids (°Brix) of Ready-to-Drink beverages from date palm extract
 520 during Storage at 4°C

| Storage (week) ^{ns} | Treatments | | | | | |
|---------------------------------|---------------------------|----------|----------|-----------------------------|----------|----------|
| | Transparent glass bottles | | | Amber-colored glass bottles | | |
| | Control | LTLT | HTST | Control | LTLT | HTST |
| 0 | 7.2±0.06 | 6.9±0.06 | 6.9±0.06 | 7.2±0.06 | 6.9±0.06 | 6.9±0.06 |
| 1 | 7.1±0.10 | 6.8±0.06 | 6.9±0.01 | 7.2±0.06 | 6.9±0.06 | 6.9±0.01 |
| 2 | 7.1±0.06 | 6.8±0.06 | 6.8±0.06 | 7.2±0.12 | 6.9±0.06 | 6.9±0.10 |
| 3 | 7.0±0.06 | 6.8±0.06 | 6.8±0.06 | 7.1±0.10 | 6.9±0.06 | 6.9±0.10 |
| 4 | 7.0±0.10 | 6.8±0.06 | 6.8±0.01 | 7.1±0.06 | 6.9±0.12 | 6.9±0.06 |
| 5 | 6.9±0.01 | 6.8±0.06 | 6.8±0.01 | 7.1±0.10 | 6.9±0.10 | 6.9±0.01 |
| 6 | 6.9±0.06 | 6.8±0.06 | 6.8±0.06 | 7.0±0.12 | 6.8±0.17 | 6.9±0.10 |
| 7 | 6.7±0.06 | 6.8±0.10 | 6.8±0.06 | 6.8±0.38 | 6.8±0.20 | 6.9±0.12 |
| 8 | 6.6±0.06 | 6.8±0.01 | 6.8±0.06 | 6.7±0.15 | 6.8±0.17 | 6.9±0.10 |
| 9 | 6.6±0.06 | 6.8±0.06 | 6.8±0.01 | 6.7±0.15 | 6.8±0.10 | 6.8±0.17 |

521 High temperature-short time (HTST, temperature 72°C, 20 sec),

522 Low temperature-long time (LTLT, temperature 63°C, 30 min)

523 “ns” indicates no significantly ($p>0.05$) different in each row.

524 Control: (date palm extract (70%): Bael fruit juice (15%): Jujube juice (15%)).

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531 **Table 4.** Effects of packaging and pasteurization on color values of Ready-to-Drink beverages from date palm extract during Storage at
 532 4°C

| | Treatments | | | | | |
|-------------|----------------------------|----------------------------|-----------------------------|-----------------------------|----------------------------|-----------------------------|
| | Transparent glass bottles | | | Amber-colored glass bottles | | |
| | Control | LTLT | HTST | Control | LTLT | HTST |
| L* | | | | | | |
| 0 | 58. 61±1. 51 ^a | 52. 14±1. 99 ^c | 55. 14±2. 99 ^b | 58. 61±1. 51 ^a | 52. 14±1. 99 ^c | 55. 14±2. 99 ^b |
| 1 | 56. 21±2. 01 ^a | 51. 21±0. 01 ^b | 54. 21±3. 01 ^a | 57. 71±0. 51 ^a | 51. 56±1. 57 ^b | 54. 87±2. 67 ^a |
| 2 | 55. 71±1. 51 ^a | 50. 92±0. 04 ^d | 53. 71±0. 51 ^{bcd} | 57. 21±0. 01 ^a | 51. 06±1. 07 ^{cd} | 54. 67±1. 55 ^{abc} |
| 3 | 55. 21±11. 01 ^b | 50. 21±0. 01 ^c | 53. 65±0. 47 ^b | 57. 02±0. 18 ^a | 50. 56±0. 57 ^c | 54. 72±0. 01 ^b |
| 4 | 54. 71±0. 51 ^a | 50. 71±0. 51 ^c | 52. 71±0. 49 ^{bc} | 57. 36±0. 64 ^a | 51. 68±2. 46 ^{bc} | 53. 00±0. 11 ^{bc} |
| 5 | 53. 71±0. 49 ^b | 49. 93±0. 05 ^d | 51. 77±0. 55 ^c | 56. 16±1. 05 ^a | 49. 93±0. 06 ^d | 53. 90±0. 01 ^b |
| 6 | 53. 03±0. 18 ^c | 48. 88±0. 10 ^e | 50. 93±0. 39 ^d | 55. 93±0. 28 ^a | 48. 93±0. 06 ^e | 54. 55±0. 34 ^b |
| 7 | 51. 03±0. 18 ^b | 46. 84±0. 06 ^c | 53. 71±1. 49 ^a | 54. 93±0. 72 ^a | 48. 01±0. 02 ^c | 52. 65±0. 25 ^a |
| 8 | 50. 23±0. 02 ^c | 45. 51±0. 39 ^e | 49. 68±0. 36 ^c | 53. 88±0. 67 ^a | 47. 51±0. 48 ^d | 51. 70±0. 30 ^b |
| 9 | 48. 73±0. 52 ^c | 44. 77±0. 35 ^e | 48. 73±0. 09 ^c | 52. 88±0. 33 ^a | 46. 73±0. 29 ^d | 50. 58±0. 18 ^b |
| a*ns | | | | | | |
| 0 | 28. 66±0. 02 | 29. 46±0. 01 | 29. 70±0. 01 | 28. 66±0. 02 | 29. 46±0. 01 | 29. 70±0. 01 |
| 1 | 29. 14±20. 50 | 29. 54±0. 01 | 29. 74±0. 02 | 29. 16±0. 52 | 29. 62±0. 01 | 29. 72±0. 01 |
| 2 | 29. 16±0. 48 | 30. 29±0. 15 | 29. 86±0. 02 | 29. 67±0. 03 | 29. 67±0. 02 | 29. 92±0. 05 |
| 3 | 29. 22±0. 50 | 30. 46±0. 02 | 29. 97±0. 02 | 29. 70±0. 01 | 29. 68±0. 01 | 29. 73±0. 04 |
| 4 | 29. 32±0. 01 | 30. 45±0. 01 | 30. 27±0. 03 | 29. 16±0. 52 | 29. 56±0. 04 | 30. 10±0. 01 |
| 5 | 29. 52±0. 16 | 30. 96±0. 52 | 30. 33±0. 01 | 29. 74±0. 02 | 29. 71±0. 01 | 30. 03±0. 02 |
| 6 | 29. 65±0. 04 | 30. 99±0. 49 | 29. 78±0. 04 | 29. 82±0. 01 | 29. 72±0. 02 | 29. 97±0. 02 |
| 7 | 30. 15±0. 47 | 31. 05±0. 44 | 30. 15±0. 01 | 29. 84±0. 01 | 29. 79±0. 05 | 30. 14±0. 01 |
| 8 | 30. 25±0. 36 | 31. 47±0. 05 | 29. 88±0. 06 | 29. 94±0. 01 | 29. 89±0. 04 | 30. 17±0. 02 |
| 9 | 30. 75±0. 14 | 32. 57±0. 95 | 30. 06±0. 14 | 30. 02±0. 01 | 29. 96±0. 03 | 30. 27±0. 28 |
| b* | | | | | | |
| 0 | 70. 59±0. 02 ^a | 67. 52±1. 98 ^b | 69. 98±0. 54 ^a | 70. 59±0. 02 ^a | 67. 52±1. 98 ^b | 69. 98±0. 54 ^a |
| 1 | 70. 56±0. 01 ^a | 67. 50±0. 01 ^c | 69. 46±0. 02 ^b | 69. 86±0. 08 ^b | 67. 44±2. 04 ^c | 69. 46±0. 52 ^b |
| 2 | 70. 52±0. 01 ^a | 67. 49±0. 01 ^{bc} | 69. 40±0. 05 ^a | 69. 84±0. 09 ^a | 67. 32±2. 01 ^c | 69. 26±0. 52 ^a |
| 3 | 70. 51±0. 01 ^a | 67. 29±0. 06 ^c | 68. 97±0. 47 ^{bc} | 69. 82±0. 06 ^a | 67. 30±2. 01 ^c | 69. 31±0. 47 ^a |
| 4 | 70. 46±0. 01 ^a | 67. 39±0. 01 ^c | 68. 75±0. 55 ^b | 69. 85±0. 09 ^a | 67. 46±0. 02 ^c | 68. 86±0. 02 ^b |

| | | | | | | |
|-----------|-------------------------|-------------------------|-------------------------|-------------------------|--------------------------|-------------------------|
| 5 | 70.33±0.02 ^a | 67.16±0.03 ^c | 68.74±0.54 ^b | 69.77±0.0 ^a | 67.21±2.00 ^{bc} | 68.91±0.03 ^b |
| 6 | 70.27±0.02 ^a | 67.04±0.01 ^c | 68.66±0.46 ^b | 69.22±0.52 ^a | 67.11±1.20 ^{bc} | 69.19±0.45 ^a |
| 7 | 70.15±0.04 ^a | 66.97±0.02 ^b | 68.81±0.61 ^a | 69.13±0.43 ^a | 66.81±0.90 ^b | 68.82±0.02 ^a |
| 8 | 70.11±0.02 ^a | 66.86±0.02 ^c | 68.62±0.42 ^b | 69.08±0.38 ^a | 66.77±0.86 ^c | 68.77±0.03 ^b |
| 9 | 70.03±0.02 ^a | 66.29±0.09 ^c | 68.22±0.20 ^b | 69.05±0.35 ^a | 66.66±0.75 ^c | 68.67±0.07 ^b |
| ΔE | | | | | | |
| 0 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| 1 | 2.48±0.59 | 2.90±0.63 ^a | 1.16±0.21 ^c | 1.64±0.42 ^{bc} | 0.62±0.40 ^c | 0.65±0.14 ^c |
| 2 | 2.98±0.09 ^a | 3.06±0.81 ^a | 2.57±1.50 ^b | 2.21±0.97 ^b | 1.17±0.86 ^c | 1.64±0.41 ^c |
| 3 | 3.49±0.40 ^a | 3.46±0.97 ^a | 2.78±1.72 ^b | 2.40±1.14 ^b | 1.68±1.34 ^c | 3.06±0.42 ^a |
| 4 | 3.96±0.98 ^a | 3.52±0.9 ^b | 3.78±2.59 ^a | 2.50±1.00 ^c | 2.07±0.16 ^c | 3.16±2.15 ^b |
| 5 | 5.01±1.92 ^a | 3.85±0.72 ^b | 4.00±3.31 ^b | 3.26±1.92 ^c | 2.35±1.93 ^d | 3.19±1.32 ^c |
| 6 | 5.69±1.64 ^a | 4.47±1.00 ^b | 4.41±3.52 ^b | 3.34±1.64 ^c | 3.48±1.79 ^c | 3.43±0.59 ^c |
| 7 | 7.74±1.74 ^a | 6.07±1.39 ^b | 4.72±1.64 ^c | 4.14±0.85 ^{cd} | 4.48±1.65 ^c | 3.53±2.45 ^d |
| 8 | 8.54±1.52 ^a | 7.30±1.26 ^b | 5.64±2.77 ^c | 5.14±0.87 ^c | 5.02±2.11 ^c | 3.89±3.07 ^d |
| 9 | 10.12±0.92 ^a | 8.57±1.40 ^b | 6.66±3.14 ^c | 6.10±1.81 ^{cd} | 5.71±1.43 ^d | 4.81±3.15 ^e |

533 High temperature-short time (HTST, temperature 72°C, 20 sec),
 534 Low temperature-long time (LTLT, temperature 63°C, 30 min)
 535 “ns” indicates no significantly ($p>0.05$) different in each row.
 536 Control: (date palm extract (70%): Quince juice (15%): Jujube juice (15%)).
 537 Data are presented as mean ± Standard Deviation
 538 Different letters (^{a-e}) mean the significantly differences ($p\leq 0.05$) in each row.

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546 **Table 5.** Effects of packaging and pasteurization on functional characteristics of Ready-to-Drink beverages from date palm extract
 547 during Storage at 4°C

| Storage (week) | Treatments | | | | | |
|-------------------|------------------------------|------------------------------|-------------------------------|------------------------------|------------------------------|------------------------------|
| | Transparent glass bottles | | | Amber-colored glass bottles | | |
| | Control | LTLT | HTST | Control | LTLT | HTST |
| TPC | | | | | | |
| 0 | 1174. 67±10. 41 ^a | 1151. 33±7. 64 ^b | 1169. 67±7. 64 ^a | 1174. 67±10. 41 ^a | 1151. 33±7. 64 ^b | 1169. 67±7. 64 ^a |
| 1 | 1066. 33±7. 64 ^{cd} | 1038. 00±18. 03 ^d | 1073. 00±13. 23 ^{bc} | 1103. 00±15. 00 ^a | 1124. 67±10. 41 ^a | 1126. 33±7. 64 ^a |
| 2 | 963. 00±5. 00 ^b | 946. 33±7. 64 ^b | 969. 67±10. 41 ^b | 1056. 33±15. 28 ^a | 1079. 67±12. 58 ^a | 1081. 33±10. 41 ^a |
| 3 | 874. 67±7. 64 ^b | 853. 00±5. 00 ^b | 891. 33±10. 41 ^b | 1006. 33±7. 64 ^a | 1024. 67±7. 64 ^a | 1033. 00±10. 00 ^a |
| 4 | 781. 33±7. 64 ^{cd} | 768. 00±13. 23 ^d | 804. 67±10. 41 ^c | 956. 33±7. 64 ^b | 983. 00±10. 00 ^a | 984. 67±7. 64 ^a |
| 5 | 688. 00±10. 00 ^{bc} | 668. 00±5. 00 ^c | 706. 33±7. 64 ^b | 861. 33±5. 77 ^a | 881. 33±12. 58 ^a | 883. 00±10. 00 ^a |
| 6 | 603. 00±5. 00 ^{cd} | 591. 33±7. 64 ^d | 618. 00±13. 23 ^c | 766. 33±7. 64 ^b | 793. 00±10. 00 ^a | 803. 00±5. 00 ^a |
| 7 | 561. 33±5. 77 ^{cd} | 556. 33±7. 64 ^d | 586. 33±10. 41 ^c | 671. 33±12. 58 ^b | 691. 33±10. 41 ^a | 701. 33±7. 64 ^a |
| 8 | 496. 33±7. 64 ^{bc} | 473. 00±13. 23 ^c | 516. 33±12. 58 ^b | 618. 00±13. 23 ^a | 628. 00±10. 00 ^a | 638. 00±13. 23 ^a |
| 9 | 381. 33±17. 56 ^c | 384. 67±12. 58 ^{bc} | 419. 67±12. 58 ^b | 556. 33±7. 64 ^a | 574. 67±15. 28 ^a | 586. 33±15. 28 ^a |
| TCC | | | | | | |
| 0 | 7. 22±0. 07 ^a | 7. 11±0. 01 ^b | 7. 18±0. 01 ^a | 7. 22±0. 07 ^a | 7. 11±0. 01 ^b | 7. 18±0. 01 ^a |
| 1 | 6. 05±0. 02 ^b | 6. 17±0. 07 ^b | 6. 13±0. 02 ^b | 6. 96±0. 05 ^a | 6. 98±0. 17 ^a | 7. 06±0. 04 ^a |
| 2 | 5. 50±0. 01 ^c | 5. 59±0. 03 ^c | 5. 65±0. 06 ^{bc} | 5. 78±0. 01 ^a | 5. 82±0. 04 ^a | 5. 97±0. 09 ^a |
| 3 | 4. 52±0. 01 ^c | 4. 62±0. 02 ^d | 4. 72±0. 03 ^c | 5. 25±0. 02 ^b | 5. 29±0. 04 ^b | 5. 38±0. 06 ^a |
| 4 | 3. 57±0. 01 ^d | 3. 61±0. 02 ^d | 3. 64±0. 01 ^d | 4. 86±0. 03 ^c | 4. 94±0. 03 ^b | 5. 03±0. 05 ^a |
| 5 | 2. 78±0. 07 ^c | 2. 81±0. 05 ^c | 2. 88±0. 02 ^c | 4. 31±0. 05 ^b | 4. 41±0. 01 ^a | 4. 53±0. 05 ^a |
| 6 | 2. 58±0. 04 ^c | 2. 63±0. 05 ^c | 2. 67±0. 01 ^c | 3. 72±0. 01 ^b | 3. 79±0. 05 ^a | 3. 82±0. 02 ^a |
| 7 | 1. 40±0. 01 ^d | 1. 45±0. 02 ^d | 1. 57±0. 04 ^c | 3. 62±0. 01 ^b | 3. 69±0. 05 ^{ab} | 3. 71±0. 03 ^a |
| 8 | 0. 90±0. 03 ^c | 0. 95±0. 02 ^{bc} | 1. 01±0. 05 ^b | 3. 55±0. 02 ^a | 3. 58±0. 01 ^a | 3. 60±0. 03 ^a |
| 9 | 0. 45±0. 02 ^d | 0. 50±0. 02 ^{cd} | 0. 54±0. 01 ^c | 3. 16±0. 03 ^b | 3. 21±0. 05 ^{ab} | 3. 25±0. 03 ^a |
| DPPH | | | | | | |
| 0 | 1448. 96±9. 55 ^a | 1421. 88±6. 25 ^b | 1436. 46±9. 55 ^a | 1448. 96±9. 55 ^a | 1421. 88±6. 25 ^b | 1436. 46±9. 55 ^a |
| 1 | 1317. 71±26. 02 ^b | 1305. 21±15. 73 ^b | 1321. 88±16. 54 ^b | 1369. 79±13. 01 ^a | 1371. 88±12. 50 ^a | 1382. 29±15. 73 ^a |
| 2 | 1180. 21±15. 73 ^b | 1194. 79±13. 01 ^b | 1213. 33±31. 81 ^b | 1311. 46±26. 02 ^a | 1309. 38±12. 50 ^a | 1321. 88±12. 50 ^a |
| 3 | 1128. 13±22. 53 ^b | 1094. 79±26. 02 ^b | 1138. 54±15. 73 ^b | 1240. 63±12. 50 ^a | 1263. 54±15. 73 ^a | 1288. 54±9. 55 ^a |
| 4 | 1059. 38±28. 64 ^b | 1023. 96±21. 95 ^b | 1076. 04±19. 09 ^b | 1184. 38±12. 50 ^a | 1196. 88±12. 50 ^a | 1207. 29±26. 02 ^a |
| 5 | 1001. 04±23. 66 ^b | 934. 38±12. 50 ^c | 1023. 96±15. 73 ^b | 1121. 88±12. 50 ^a | 1134. 38±12. 50 ^a | 1144. 79±26. 02 ^a |
| 6 | 873. 96±26. 02 ^b | 869. 79±15. 73 ^b | 886. 46±9. 55 ^b | 1059. 38±12. 50 ^a | 1071. 88±12. 50 ^a | 1082. 29±26. 02 ^a |
| 7 | 757. 29±19. 09 ^b | 748. 96±20. 09 ^b | 761. 46±13. 01 ^b | 936. 46±20. 09 ^a | 944. 79±19. 09 ^a | 961. 46±13. 01 ^a |
| 8 | 694. 79±19. 09 ^b | 684. 38±16. 54 ^b | 711. 46±7. 22 ^b | 809. 38±16. 54 ^a | 819. 79±19. 09 ^a | 836. 46±7. 22 ^a |
| 9 | 638. 54±13. 01 ^b | 640. 63±25. 00 ^b | 646. 88±6. 25 ^b | 744. 79±19. 09 ^a | 751. 04±36. 62 ^a | 763. 54±13. 01 ^a |

FRAP

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|----------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| 0 | 1430. 26±14. 43 ^a | 1419. 55±4. 12 ^b | 1427. 88±10. 31 ^a | 1430. 26±14. 43 ^a | 1419. 55±4. 12 ^b | 1427. 88±10. 31 ^a |
| 1 | 1323. 12±17. 62 ^c | 1345. 74±4. 12 ^{bc} | 1369. 55±8. 99 ^{ab} | 1381. 45±5. 46 ^a | 1385. 02±8. 99 ^a | 1393. 36±12. 88 ^a |
| 2 | 1257. 64±7. 14 ^c | 1287. 40±12. 54 ^b | 1294. 55±8. 99 ^b | 1283. 83±8. 99 ^b | 1323. 12±12. 54 ^a | 1325. 50±3. 57 ^a |
| 3 | 1150. 50±7. 14 ^d | 1183. 83±5. 46 ^c | 1196. 93±3. 57 ^b | 1186. 21±7. 14 ^c | 1212. 40±7. 43 ^b | 1248. 12±14. 87 ^a |
| 4 | 943. 36±3. 57 ^d | 962. 40±14. 43 ^{cd} | 986. 21±6. 19 ^{bc} | 981. 45±10. 91 ^{bc} | 1000. 50±10. 71 ^b | 1024. 31±5. 46 ^a |
| 5 | 857. 64±6. 19 ^d | 860. 02±10. 31 ^d | 912. 40±5. 46 ^c | 933. 83±17. 62 ^{bc} | 954. 07±10. 71 ^b | 967. 17±14. 87 ^a |
| 6 | 819. 55±5. 46 ^c | 825. 50±9. 45 ^c | 862. 40±17. 98 ^b | 855. 26±5. 46 ^b | 861. 21±9. 45 ^b | 896. 93±9. 45 ^a |
| 7 | 723. 12±10. 91 ^d | 729. 07±6. 19 ^d | 758. 83±14. 43 ^c | 819. 55±5. 46 ^b | 825. 50±9. 45 ^b | 857. 64±7. 14 ^a |
| 8 | 677. 88±7. 43 ^c | 688. 60±8. 99 ^c | 699. 31±5. 46 ^c | 796. 93±7. 14 ^b | 812. 40±5. 46 ^a | 827. 88±11. 48 ^a |
| 9 | 588. 60±10. 91 ^c | 594. 55±14. 43 ^c | 613. 60±8. 99 ^c | 754. 07±3. 57 ^b | 761. 21±14. 29 ^a | 786. 21±3. 57 ^a |

548 TPC: total phenolic compound (mg GAE/100 mL = mg gallic acid equivalent/100 mL)

549 TCC: total carotenoid content (mg β -CE/100 mL = mg β -carotene equivalent/100 mL)

550 DPPH: 2,2-diphenyl-1-picrylhydrazyl (mM trolox/100 mL)

551 FRAP: ferric reducing antioxidant power (mM trolox/100 mL)

552 High temperature-short time (HTST, temperature 72°C, 20 sec),

553 Low temperature-long time (LTLT, temperature 63°C, 30 min)

554 “ns” indicates no significantly ($p>0.05$) different in each row.

555 Control: (date palm extract (70%): Bael fruit juice (15%): Jujube juice (15%)).

556 Data are presented as mean \pm Standard Deviation

557 Different letters (^{a-e}) mean the significantly differences ($p\leq 0.05$) in each row.

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566 **Table 6.** Effects of packaging and pasteurization on microbial and yeast and mold counts of Ready-to-Drink beverages from date palm
 567 extract during Storage at 4°C

| Storage (week) | Treatments | | | | | |
|-----------------------|---------------------------|-------------|-------------|-----------------------------|-------------|-------------|
| | Transparent glass bottles | | | Amber-colored glass bottles | | |
| | Control | LTLT | HTST | Control | LTLT | HTST |
| Total bacteria | | | | | | |
| 0 | 1. 39±0. 12 | ND | ND | 1. 39±0. 12 | ND | ND |
| 1 | 2. 39±0. 12 | ND | ND | 2. 09±0. 12 | ND | ND |
| 2 | 3. 39±0. 12 | ND | ND | 3. 11±0. 10 | ND | ND |
| 3 | 4. 02±0. 09 | ND | ND | 3. 57±0. 04 | ND | ND |
| 4 | 4. 52±0. 74 | ND | ND | 4. 02±0. 09 | ND | ND |
| 5 | 5. 27±0. 02 | ND | ND | 4. 29±0. 08 | ND | ND |
| 6 | 5. 41±0. 02 | 1. 10±0. 14 | 1. 00±0. 01 | 5. 06±0. 08 | 1. 02±0. 03 | ND |
| 7 | 6. 04±0. 06 | 2. 10±0. 14 | 1. 81±0. 05 | 5. 35±0. 07 | 1. 93±0. 04 | 1. 65±0. 07 |
| 8 | 6. 22±0. 06 | 3. 21±0. 13 | 2. 80±0. 14 | 5. 98±0. 03 | 2. 74±0. 06 | 2. 24±0. 34 |
| 9 | 7. 06±0. 08 | 4. 22±0. 06 | 3. 22±0. 06 | 6. 18±0. 10 | 3. 98±0. 03 | 2. 98±0. 03 |
| Yeast and mold | | | | | | |
| 0 | 2. 40±0. 13 | ND | ND | 2. 40±0. 13 | ND | ND |
| 1 | 2. 95±0. 07 | ND | ND | 2. 69±0. 13 | ND | ND |
| 2 | 3. 28±0. 03 | ND | ND | 2. 99±0. 12 | ND | ND |
| 3 | 3. 80±0. 14 | ND | ND | 3. 28±0. 03 | ND | ND |
| 4 | 4. 16±0. 06 | ND | ND | 3. 71±0. 15 | ND | ND |
| 5 | 4. 24±0. 09 | ND | ND | 4. 17±0. 12 | ND | ND |
| 6 | 4. 63±0. 21 | 1. 00±0. 01 | ND | 4. 31±0. 08 | ND | ND |
| 7 | 5. 04±0. 06 | 1. 85±0. 21 | 1. 50±0. 28 | 4. 80±0. 14 | 1. 15±0. 21 | 1. 00±0. 01 |
| 8 | 5. 22±0. 06 | 2. 45±0. 21 | 2. 24±0. 34 | 5. 02±0. 03 | 2. 19±0. 16 | 2. 09±0. 12 |

| | 9 | 6. 04±0. 06 | 3. 35±0. 07 | 3. 04±0. 06 | 5. 16±0. 02 | 2. 80±0. 14 | 2. 57±0. 12 |
|------------------------------|----|-------------|-------------|-------------|-------------|-------------|-------------|
| Coliform (MPN/mL) | | | | | | | |
| 0 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 1 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 2 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 4 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 5 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 6 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 7 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 8 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 9 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |

568 High temperature-short time (HTST, temperature 72°C, 20 sec),
 569 Low temperature-long time (LTLT, temperature 63°C, 30 min)
 570 “ns” indicates no significantly (p>0.05) different in each row.
 571 Control: (date palm extract (70%): Bael fruit juice (15%): Jujube juice (15%)).
 572 Data are presented as mean ± Standard Deviation
 573 ND: not detected.

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Data availability Statement

The data in the current study are available from the corresponding author upon reasonable request.

