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Comparison of the phenolic profiles and physicochemical properties of different varieties of thermally processed canned lychee pulp†

Zhineng Wang,‡[abc] Guangxu Wu,‡[b] Bin Shu,[bc] Fei Huang,[c] Lihong Dong,[c] Ruifen Zhang[c] and Dongxiao Su *[ab]

Lychee pulp is rich in phenolics and has a variety of biological activities. However, the changes in the phenolic profile under heat treatment are unknown. The effect of the heat treatment temperature on commercial varieties (*Guiwei* and *Nuomici*) of canned lychee was investigated by comparing samples that were either unheated (UH), underwent 70 °C heat treatment (HT70) or underwent 121 °C heat treatment (HT121) and then were stored at room temperature. The results showed that the total phenolic content (TPC), total flavonoid content (TFC) and antioxidant activity of the UH, HT70 and HT121 samples were significantly decreased after storage at room temperature for 9 d, 13 d and 25 d, respectively. However, the TPC, TFC and antioxidant activity of HT121 canned lychee were still significantly higher than those of the UH and HT70 samples. However, the texture characteristics of the HT121 samples were worse than those of the UH and HT70 samples, and the color of the canned lychee was darker after the HT121 treatment. Nine individual phenolic compounds were detected in the canned lychee by HPLC-DAD. The gallic acid content was increased after HT121 treatment. In particular, (−)-gallocatechin was generated by HT121 thermal processing. However, after storage at room temperature for 9 d, the contents of (−)-gallocatechin in canned *Guiwei* and *Nuomici* were decreased by 96.27% and 94.04%, respectively, and (−)-gallocatechin disappeared after 25 d. In summary, the phenolic contents and antioxidant activity of canned lychee are increased by high-temperature treatment.

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1. Introduction

Phenolics are a diverse group of plant secondary metabolites. Epidemiological studies have shown that the regular intake of fruits and vegetables rich in phenolics prevents some major chronic diseases, including cancer, cardiovascular diseases and neurodegenerative diseases.[1–3] Lychee (*Litchi chinensis* Sonn.) is a typical tropical and subtropical fruit that is cultivated all over the world, especially in China, Vietnam, Indonesia, Thailand, the Philippines, Hawaii and the USA, and has become a cash crop in many countries. Furthermore, lychee is a low-acidity fruit with a pH of 5. It has a bright red color at maturity and a highly desirable taste.[4] Lychee pulp is rich in phenolic acids and flavonoids.[5] Quercetin-3-rutinose-7-rhamnoside, epicatechin, gallic acid, ferulic acid, procyanidin B2 and rutin are the major phenolic compounds in lychee pulp,[5–7] and it has been reported that lychee pulp phenolics have antioxidant, anti-inflammatory, hypoglycemic and lipid-lowering effects.[7]

Fruits have a short preservation period and are extremely perishable due to their high water content and the presence of microflora. Fruit canning retains the original texture of the pulp, and canned fruit is easily accessible and available throughout the year. Canned fruits can significantly promote fruit consumption and are a convenient way to promote fruit intake, as they generally deliver consistently good nutritional quality.[8] In developing countries, canned food is an important part of some people's daily diet. The canning process depends on heat treatment to kill microorganisms and increase the shelf life of commodities.[9] Canned fruits are normally pasteurized at high temperatures for a long period of time.[10] Previous studies have shown that canned peaches could be stored at 22 °C for 90 d after heat treatment at 90 °C, and fruit salad could be stored at 25 °C for 98 d after heat treatment at 70 °C or 80 °C.[10,11] Furthermore, recent studies have shown that thermally processed foods, especially fruits and vegetables, undergo various chemical changes during heat treatment, increasing the biological activities of the phytochemical compounds in fruits and

[a]*School of Chemistry and Chemical Engineering, Guangzhou University, Guangzhou 510006, P. R. China. E-mail: dongxsu@126.com; Fax: +86-20-39366903; Tel: +86-20-39366902*

[b]*College of Life Science, Yangtze University, Jingzhou 434025, P. R. China*

[c]*Sericultural & Agri-Food Research Institute Guangdong Academy of Agricultural Sciences, Key Laboratory of Functional Foods, Ministry of Agriculture and Rural Affairs, Guangdong Key Laboratory of Agricultural Products Processing, Guangzhou 510610, P. R. China*

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‡ These two authors should be considered joint first authors.

vegetables; for example, the free flavonoid contents in shiitake mushrooms heat treated at 121 °C and 100 °C were significantly increased compared to those of raw shiitake.[12] Therefore, heat-processed foods can be considered to have higher biological activities than their raw counterparts.

To date, the changes in the texture characteristics, phenolic composition and antioxidant activity of canned lychee treated at different temperatures and then stored at room temperature have rarely been reported. The aim of the present study was to investigate the effects of different heat treatment temperatures on (1) the composition and contents of phenolic compounds in different varieties of lychee; (2) the antioxidant activity of different varieties of lychee; and (3) the texture characteristics and color parameters of different varieties of lychee.

2. Materials and methods

2.1 Materials

Fresh ripe lychee (cv *Guiwei* and *Nuomici*) fruits at commercial maturity with a bright red pericarp were purchased from a local fruit market in Guangzhou, China.

Gallic acid, (−)-gallocatechin (GC), procyanidin B2, vanillic acid, lilac acid, procyanidin A2, ferulic acid, and rutin were purchased from Shanghai Yuanye Biotechnology Co., Ltd. (Shanghai, China). Quercetin-3-rutinose-7-rhamnoside was prepared using a method previously reported by this laboratory.[6] A ferric reducing antioxidant power (FRAP) kit was purchased from the Nanjing Jiancheng Bioengineering Institute (Nanjing, China). Folin–Ciocalteu reagent was purchased from Macklin Reagent Co., Ltd. (Shanghai, China). 2′,7′-Dichlorofluorescin diacetate, fluorescein disodium salt and 2′,2′-azobis (2-amidinopropane) dihydrochloride (AAPH) were obtained from Xiya Reagent Co., Ltd. (Chengdu, China). Trisodium citrate dihydrate and sodium phosphate monobasic dihydrate were purchased from the Tianjin Damao Chemical Reagent Factory (Tianjin, China). HPLC-grade methanol, acetic acid and acetonitrile were purchased from Thermo Fisher Scientific (Waltham, MA).

2.2 Preparation of canned lychee

Trisodium citrate dihydrate (0.1 mol L^{-1}) and sodium phosphate monobasic dihydrate (0.2 mol L^{-1}) were mixed in a ratio of 42.2 : 7.8, and then, 13% sucrose was mixed into the solution.

Lychee fruits were cleaned with tap water, and the peel and kernel were removed manually. Lychee pulp (60.00 ± 2.00 g) was canned in 30 mL of the above sugar solution in a glass container. The heat treatments were carried out as described by Choi[12] with slight modifications: heat treatment for 30 min at 70 °C in a water bath (WA12, Wiggens, Beijing, China) or at 121 °C in a vertical pressure steam sterilizer (LS-75HD, Jiangyin Binjiang Medical Equipment Co., Ltd., China). The heat treatments at 70 °C and 121 °C were denoted HT70 and HT121, respectively. Unheated (UH) lychee pulp was used as the control. Usually, as the heat treatment temperature increases, the shelf life of the treated food also increases. Thus, the untreated canned lychee was stored at room temperature and sampled at 0, 3, 5, 7, and 9 d. The HT70 samples were stored at room temperature and sampled at 0, 5, 9, and 13 d. The HT121 samples were stored at room temperature and sampled at 0, 9, 17, and 25 d. The samples were crushed and centrifuged, and the supernatant was removed and stored in a refrigerator at −80 °C for HPLC, total phenolic content (TPC), total flavonoid content (TFC), FRAP and oxygen radical absorbance capacity (ORAC) analysis.

2.3 Determination of the TPC and TFC

The TPC and TFC were determined using the method described by Dewanto.[13] Gallic acid was used as the TPC standard. The TPC of canned lychee was expressed as mg GAE/100 g FW. Rutin was used as the TFC standard. The TFC of canned lychee was expressed as mg RE/100 g FW. The results are presented as the mean ± standard deviation (SD) of three replications obtained from three samples.

2.4 Analytical HPLC-DAD analysis

The phenolic profile composition of the canned lychee was identified using the reversed-phase HPLC-DAD method described by Zhang *et al.*[14] on an Agilent 1260 HPLC system (Agilent Technologies Deutschland GmbH, Oberhaching, Germany) equipped with an Agilent 1260 series DAD detector. HPLC analysis was performed using a YMC-Pack ODS-A column (250 × 4.6 mm; I.D., 5 μm; YMC Karasuma-Gojo Bldg, Japan) at 30 °C. The sample injection volume was 20 μL, and the mobile phase flow rate was 1.0 mL min^{-1}. The mobile phase included solvent A (water/acetic acid, 996 : 4, v/v) and solvent B (acetonitrile). The gradient was programed as follows: 0–40 min, 5–25% B; 40–45 min, 25–35% B; and 45–50 min, 35–50% B. Chromatographic data were detected at 280 nm. Quercetin-3-rutinose-7-rhamnoside, gallic acid, (−)-gallocatechin, procyanidin B2, vanillic acid, syringic acid, procyanidin A2, ferulic acid, and rutin were used as standards. The details of the calibration and correlation coefficients of the 9 phenolics are supplied in Table S1.† Values are expressed as μg per g of lychee pulp. The data are reported as the mean ± SD of three replications obtained from three samples.

2.5 Ferric reducing antioxidant power (FRAP) assay

The FRAP antioxidant capacity was determined according to the kit instructions as described by Su *et al.*[15] Five microliters of canned lychee sample or standard solution was added into a 96-well microplate, and then 180 μL of FRAP working solution was added. After incubation for 5 min in a microplate reader (BioTek Gen5, BioTek, USA) at 37 °C, the response at 593 nm was recorded. Ferrous sulfate was used as the standard. The FRAP results were expressed as mmol FeE/100 g FW. The results are presented as the mean ± SD of three replications obtained from three samples.

2.6 Determination of the ORAC

The ORAC assay was carried out using an Infinite M200 Pro microplate reader (TECAN Infinite 200, TECAN, Switzerland)

following the method reported by Su *et al.*[6] First, 20 μL of canned lychee sample or Trolox standard solution (concentration range, 6.25–50 μmol L^{-1}) was added into a black-walled 96-well plate. After incubation with 200 μL of 0.96 μM fluorescein in each well for 20 min, 20 μL of freshly prepared AAPH in working buffer (119 mmol L^{-1}) was added to all wells except for the control well and allowed to incubate for 10 min. Then, the response of each well was recorded with excitation at 485 nm and emission at 520 nm every 4.5 min for 35 cycles. The ORAC value was expressed as μmol TE/100 g FW. The results are reported as the mean ± SD of three replications obtained from three samples.

2.7 Textural profile analysis (TPA)

The hardness, elasticity, cohesiveness and chewiness of lychee pulp were determined using a TA-XLPLUS texture analyzer (Stable Micro Systems Ltd., UK). In TPA mode, the P50 probe (5 mm diameter) was selected to analyze the samples. The test speed, compression degree, trigger force and trigger type were 100 mm min^{-1}, 0.5 cm, 5 g and automatic, respectively. Sample selection included the exterior of the pulp, and the test was repeated three times.

2.8 Color parameter measurements

The color of the lychee pulp was measured with the CIELAB method using an Ultra Scan VIS (Hunter Lab, USA).[16] The L^*, a^*, b^* and ΔE^* values were calculated using the formula reported by Sun *et al.*[17] The values of L^* and ΔE^* indicate the lightness and total color difference, respectively. The values of a^* and b^* indicate greenness (negative) to redness (positive) and the blueness (negative) to yellowness (positive), respectively.[15] In particular, ΔE is used to distinguish between two colors according to the following scale:[18] $\Delta E < 0.2$, no perceptible difference; $0.2 < \Delta E < 0.5$, very small difference; $0.5 < \Delta E < 2$, small difference; $2 < \Delta E < 3$, fairly perceptible difference; $3 < \Delta E < 6$, perceptible difference; $6 < \Delta E < 12$, strong difference; and $\Delta E > 12$, completely different colors.

2.9 Determination of the soluble solid index

The level of soluble solids was measured as % Brix with a refractometer (PAL-1 refractometer, ATAGO, Japan), and three analyses of three samples were performed.

2.10 Statistical analysis

The data were analyzed by using the SPSS statistical package version 24.0. Data are reported as the mean ± SD of three replicates obtained from three samples. Significant differences among canned lychee samples were evaluated by one-way ANOVA followed by the Tukey test. The significance level was $p < 0.05$.

3. Results

3.1 Heat treatment enhances the TPC of canned lychee

The effects of different heat treatments (unheated, 70 °C and 121 °C) on the TPC of the different varieties of canned lychee (*Guiwei* and *Nuomici*) are shown in Fig. 1. The TPC of canned *Guiwei* was higher than that of canned *Nuomici*. The TPC of UH canned *Guiwei* and *Nuomici* decreased significantly after 3 d of storage at room temperature, and the lowest values were 35.39 mg/100 g and 30.46 mg/100 g, respectively, on the 9th day. The TPC values of HT70 canned *Guiwei* and *Nuomici* at 0 d were lower than those of the UH samples at 0 d. After 13 d of storage at room temperature, the TPCs of canned *Guiwei* and *Nuomici* decreased significantly. Similar changes in the TPC of canned lychee were observed in the HT121 group. Compared with the UH 0 d and HT70 0 d samples, the TPCs of HT121 canned *Guiwei* and *Nuomici* were increased significantly. However, after 9 d of storage at room temperature, the TPCs of HT121 canned *Guiwei* and *Nuomici* decreased by 72.31% and 66.05%, respectively. These results showed that heat treatment at 121 °C promoted the release of phenolics and generated new phenolics from canned lychee initially, but decreased with prolonged storage time. Therefore, the degradation rate of HT121-treated canned lychee was fastest in the initial stage of storage. This may be due to the high-temperature (121 °C) treatment generating a large amount of (−)-gallocatechin, which may have poor thermal stability in acidic aqueous systems and degrade rapidly in the initial stage of storage. However, the TPC of the HT121 canned lychee was still higher than those of the UH and HT70 canned lychee.

3.2 Heat treatment increases the total flavonoid content of canned lychee

Two varieties (*Guiwei* and *Nuomici*) of canned lychee were treated with heat (70 °C and 121 °C) and compared with unheated canned lychee, and the resulting changes in the TFC of the fruit are presented in Fig. 2. The TFC of canned *Guiwei* was higher than that of canned *Nuomici*, which was consistent with the TPC results. It can be deduced that the content of phenolics in canned *Guiwei* was higher than that in canned *Nuomici*. The TFC of UH canned *Guiwei* increased significantly beginning on the 3rd day of storage at room temperature and did not decrease significantly from days 3–7; however, it significantly decreased after 9 d of storage compared to that on days 3, 5 and 7 ($p < 0.05$). The TFC of canned *Guiwei* and *Nuomici* differed. The TFCs of HT70 0 d canned *Guiwei* and *Nuomici* were increased by 56.80% and 31.81%, respectively, compared with that of UH 0 d. However, the TFCs of canned *Guiwei* and *Nuomici* decreased significantly during storage at room temperature for 13 d. Compared with those of the UH 0 d samples, the TFCs of HT121 samples were increased by 128.90% and 63.15%, respectively. Compared with those of the HT70 0 d samples, the TFCs of HT121 samples were increased by 45.98% and 23.77%, respectively. However, after storage at room temperature for 25 d, the TFCs of canned *Guiwei* and *Nuomici* were at the lowest values of 25.81 mg/100 g and 20.84 mg/100 g, respectively. These

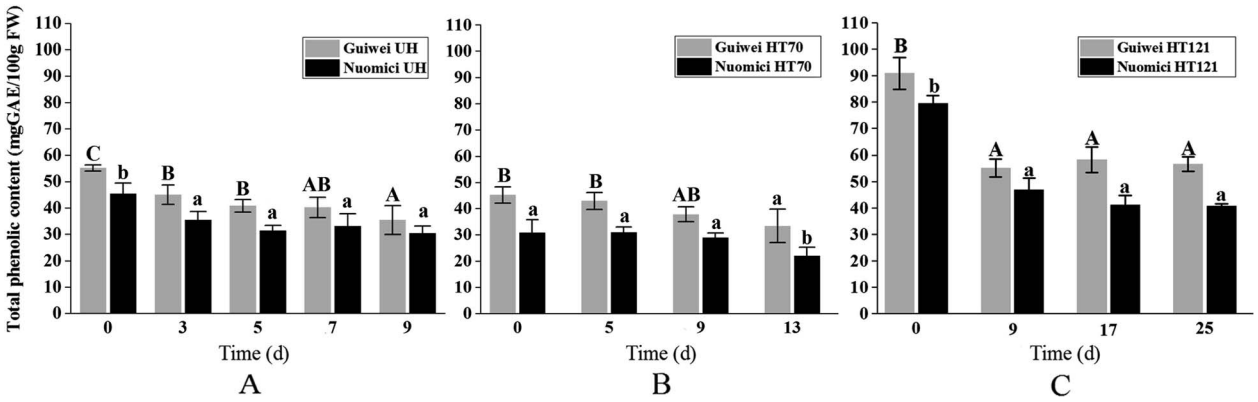

Fig. 1 Effect of the heat treatment temperature (70 °C and 121 °C) on the TPC of two commercial varieties of canned lychee pulp. Columns without a common letter for one variety are significantly different ($p < 0.05$). (A) UH, unheated; (B) HT70, 70 °C heat treatment; and (C) HT121, 121 °C heat treatment.

results showed that heat treatment was beneficial to the release of flavonoids in canned lychee, and the thermal stability of most of the original phenolic compounds in lychee pulp is good. The contents of flavonoids after 70 °C and 121 °C heat treatment were increased, but the TFC was not stable at room temperature and decreased with prolonged storage time, mainly because of the decrease in the content of newly generated (−)-gallocatechin.

3.3 Effects of heat treatment on monomeric phenolics in different varieties of canned lychee analyzed by HPLC-DAD

Phenolic compounds in canned *Guiwei* and *Nuomici* were determined by an Agilent 1260 HPLC system (Table 1). Nine individual phenolic compounds, namely, gallic acid, (−)-gallocatechin, procyanidin B2, vanillic acid, syringic acid, quercetin-3-rutinose-7-rhamnoside, procyanidin A2, ferulic acid and rutin, were detected in lychee pulp. The contents of (−)-gallocatechin and quercetin-3-rutinose-7-rhamnoside were high (>20.0 μg g^{-1}), but the contents of procyanidin B2 and procyanidin A2 were low (<1.0 μg g^{-1}). The contents of gallic acid, procyanidin B2 and procyanidin A2 increased with heat treatment and decreased as the storage time increased. Vanillic acid and syringic acid were detected in canned *Guiwei* but not in canned *Nuomici*. (−)-Gallocatechin was generated by HT121 thermal processing and accounted for 89% of the total phenolic compounds in HT121 canned lychee. However, after storage at room temperature for 9 d, the contents of (−)-gallocatechin in canned *Guiwei* and *Nuomici* decreased by 96.27% and 94.04%, respectively, and (−)-gallocatechin disappeared after 25 d. Quercetin-3-rutinose-7-rhamnoside, ferulic acid and rutin were identified in canned lychee as thermally stable monomeric phenolics and did not completely degrade at 121 °C. The contents of quercetin-3-rutinose-7-rhamnoside, ferulic acid and rutin in canned *Guiwei* were higher than those in canned *Nuomici*.

3.4 Heat treatment increases the antioxidant activity of canned lychee

The antioxidant activities of canned *Guiwei* and *Nuomici* were determined by the FRAP assay (Fig. 3). The FRAP antioxidant

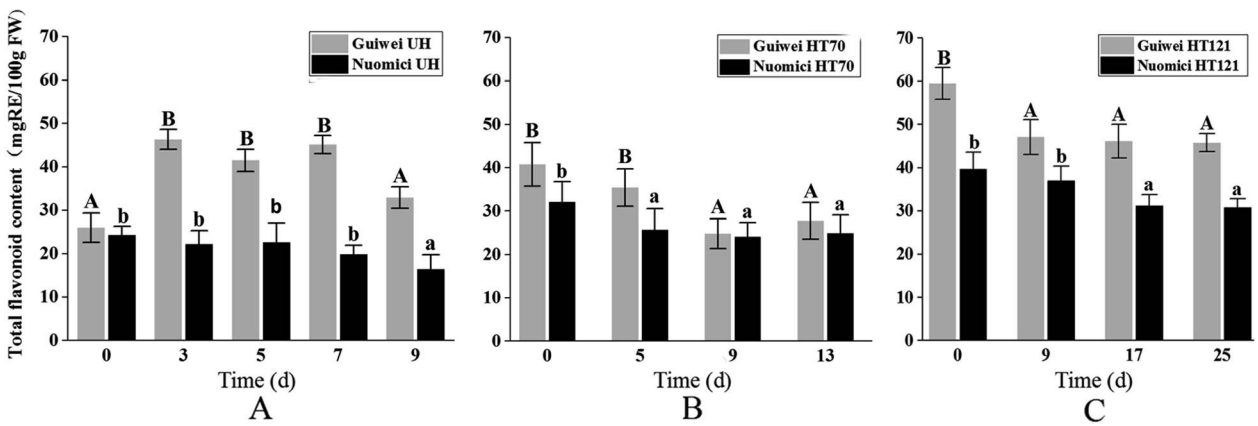

Fig. 2 Effect of the heat treatment temperature (70 °C and 121 °C) on the TFC of two commercial varieties of canned lychee pulp. Columns without a common letter for one variety are significantly different ($p < 0.05$). (A) UH, unheated; (B) HT70, 70 °C heat treatment; and (C) HT121, 121 °C heat treatment.

Table 1 Effects of heat treatment on the monomeric phenolic content of different varieties of canned lychee determined by HPLC-DAD

		Phenolic compounds (μg g^{-1} FW)									
Cultivars		Gallic acid	Procyanidin B2	(−)-Gallocatechin	Vanillic acid	Syringic acid	Quercetin-3-rutinose-7-rhamnoside	Procyanidin A2	Ferulic acid	Rutin	Total[a]
Guiwei UH	0 d	4.4 ± 0.3a	0.53 ± 0.02d	ND	ND	1.7 ± 0.2b	144 ± 5e	0.51 ± 0.03def	8 ± 1i	16 ± 3g	171 ± 6
	3 d	4.3 ± 0.5a	0.46 ± 0.03c	ND	2.2 ± 0.2a	2.65 ± 0.08c	253 ± 4i	0.38 ± 0.02c	2.21 ± 0.04def	8 ± 2cd	274 ± 8
	9 d	3.4 ± 0.3a	0.27 ± 0.04a	ND	2.1 ± 0.3a	ND	158 ± 5f	0.21 ± 0.01a	2.3 ± 0.2ef	8 ± 2cd	175 ± 5
Guiwei HT70	0 d	9 ± 1a	0.75 ± 0.01e	ND	ND	1.32 ± 0.05a	218 ± 6h	0.75 ± 0.01h	1.2 ± 0.3a	8 ± 2c	239 ± 9
	5 d	8 ± 1a	0.32 ± 0.01b	ND	2.4 ± 0.4a	2.7 ± 0.2c	164 ± 3f	0.61 ± 0.03 fg	2.44 ± 0.04f	8 ± 2cd	189 ± 3
	13 d	6.4 ± 0.7a	0.27 ± 0.05a	ND	5.0 ± 0.4a	4±1d	206 ± 8g	0.57 ± 0.02 fg	3.0 ± 0.4g	11 ± 2e	236 ± 10
Guiwei HT121	0 d	150 ± 5d	1.49 ± 0.01f	2564 ± 26c	ND	ND	161 ± 5f	0.93 ± 0.02i	5.4 ± 0.1h	12 ± 2f	2895 ± 26
	9 d	132 ± 8c	0.77 ± 0.03e	96±7a	ND	ND	71 ± 3d	0.49 ± 0.01def	1.76 ± 0.03bcd	6 ± 1b	307 ± 7
	25 d	117 ± 6b	0.23 ± 0.04a	ND	ND	ND	53 ± 3c	0.55 ± 0.07fg	1.33 ± 0.02ab	9 ± 1d	182 ± 11
Nuomici UH	0 d	7 ± 1a	ND	ND	ND	ND	49 ± 4c	0.43 ± 0.02c	1.22 ± 0.04a	4.1 ± 0.3a	62 ± 3
	3 d	6.2 ± 0.9a	ND	ND	ND	ND	67 ± 4d	0.45 ± 0.02c	1.95 ± 0.07cdef	5.5 ± 0.9b	81 ± 4
	9 d	4.0 ± 0.4a	ND	ND	ND	ND	35 ± 3b	0.31 ± 0.02b	1.9 ± 0.3cde	5.9 ± 0.8b	47 ± 3
Nuomici HT70	0 d	7.5 ± 0.7a	ND	ND	ND	ND	78 ± 5d	0.76 ± 0.01h	1.6 ± 0.3abc	3.8 ± 0.6a	92 ± 9
	5 d	8 ± 1a	ND	ND	ND	ND	75 ± 5d	0.40 ± 0.01c	2.2 ± 0.3def	6 ± 1b	91 ± 3
	13 d	4 ± 1a	ND	ND	ND	ND	55 ± 2c	0.19 ± 0.02a	2.1 ± 0.2def	ND	62 ± 2
Nuomici HT121	0 d	193 ± 11f	ND	1881 ± 30b	ND	ND	33 ± 3b	1.06 ± 0.04j	1.10 ± 0.03a	3.1 ± 0.3a	2113 ± 34
	9 d	173 ± 11e	ND	112±5a	ND	ND	31 ± 2b	0.53 ± 0.02efg	1.36 ± 0.03ab	ND	319 ± 12
	25 d	114 ± 6b	ND	ND	ND	ND	21 ± 4a	0.17 ± 0.03a	ND	ND	135 ± 8

[a] Sum of the nine individual phenolic compounds. Values that do not share a common letter in the same column are significantly different ($p < 0.05$). UH: unheated; HT70: 70 °C heat treatment; HT121: 121 °C heat treatment; means ± SD, $n = 3$.

capacity of canned *Guiwei* was higher than that of canned *Nuomici*. The antioxidant activity of HT121 0 d canned lychee was significantly higher than those of the UH 0 d and HT70 0 d samples, which was consistent with the TPC results. The antioxidant capacities of canned *Guiwei* and *Nuomici* decreased as the storage time increased. Compared with those of the UH 0 d samples, the antioxidant capacities of the UH 9 d canned *Guiwei* and *Nuomici* samples were decreased by 27.04% and 36.59%, respectively. Compared with those of the HT70 0 d samples, the antioxidant capacities of the HT70 13 d canned *Guiwei* and *Nuomici* samples were decreased by 50.52% and 67.07%, respectively. Compared with those of the HT121 0 d samples, the antioxidant capacities of the HT121 25 d canned *Guiwei* and *Nuomici* samples were decreased by 48.64% and 44.68%, respectively. However, the antioxidant activity of the HT121 samples was still higher than those of the UH 9 d samples and was not significantly lower than those of the UH 0 d samples. These results showed that the antioxidant activities of UH, HT70 and HT121 canned lychee decreased as the storage time increased, and the 121 °C heat treatment improved the antioxidant activity of canned lychee the most.

The ORAC values of canned *Guiwei* and *Nuomici* are shown in Fig. 4. The antioxidant capacity of canned *Guiwei* was significantly higher than that of canned *Nuomici*, which was consistent with the results of the FRAP assay. The TFCs of the HT121 canned *Guiwei* and *Nuomici* samples were increased by 24.75% and 18.23%, respectively, compared with those of the UH 0 h samples and by 54.53% and 52.38%, respectively, compared with those of the HT70 0 h samples. Furthermore, the antioxidant activities of the UH, HT70 and HT121 canned lychee decreased significantly with prolonged storage time ($p < 0.05$). Therefore, it can be concluded that the 121 °C heat treatment could increase antioxidant capacity of canned lychee, which was positively correlated with the TPC, by promoting the release of phenolic compounds, but as the storage time increased, the TPC and antioxidant activity both decreased significantly.

3.5 Effect of heat treatments at different temperatures on the quality of canned *Guiwei* and *Nuomici*

The texture characteristics of canned *Guiwei* and *Nuomici* lychee pulp were determined (Table 2, Fig. S1 and S2†). The hardness, elasticity, cohesiveness and chewiness of UH, HT70 and HT121 canned *Guiwei* were higher than those of canned *Nuomici*. In addition, the hardness, elasticity, cohesiveness and chewiness decreased as the heat treatment temperature increased. These results showed that heat treatment destroys the tissue structure of lychee pulp.

The soluble solid index of canned lychee after heat treatment (Fig. 5) followed a pattern of HT121 > HT70 > UH, and the values of HT70 and HT121 were significantly higher than that of UH ($p < 0.05$). Therefore, heat treatment could contribute to the dissolution of soluble solids in lychee pulp.

The ΔE^* values of HT70 and HT121 canned *Guiwei* and *Nuomici* are shown in Table 3. The ΔE^* values of HT70 canned *Guiwei* and *Nuomici* were 0.71 and 1.16, respectively. The color of HT70 canned lychee was similar to that of UH canned lychee. The ΔE^* value of canned lychee heat treated at 121 °C was between $3 < \Delta E^* < 6$, and thus, the color of HT121 canned lychee was perceptibly different from that of UH canned lychee. These results showed that heat treatment at 121 °C could lead to browning of lychee pulp (Fig. S1 and S2†), seriously affecting the appearance quality and commodity value of canned lychee.

4. Discussion

Phenolic compounds are secondary metabolites of plants and the most active antioxidant derivatives. They are considered antioxidants not only because of their ability to provide

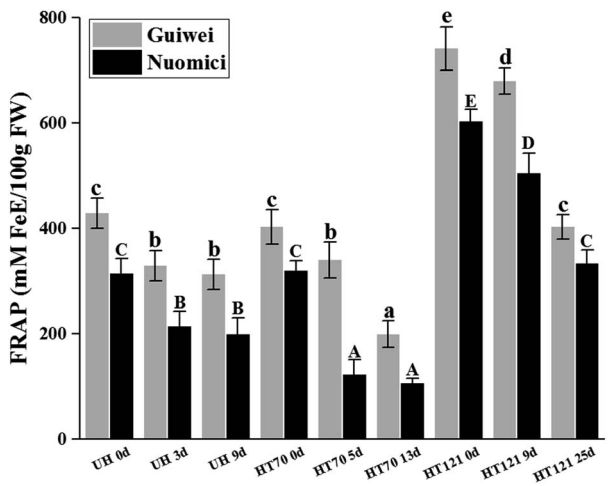

Fig. 3 Effect of the heat treatment temperature (70 °C and 121 °C) on the FRAP antioxidant capacity of two commercial varieties of canned lychee pulp. Bars labeled with different letters for one variety are significantly different ($p < 0.05$). UH, unheated; HT70, 70 °C heat treatment; and HT121, 121 °C heat treatment.

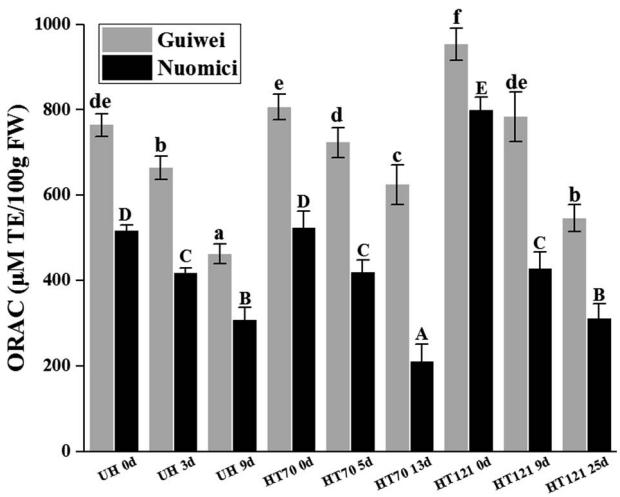

Fig. 4 Effect of the heat treatment temperature (70 °C and 121 °C) on the ORAC antioxidant capacity of two commercial varieties of canned lychee pulp. Bars labeled with different letters for one variety are significantly different ($p < 0.05$). UH, unheated; HT70, 70 °C heat treatment; and HT121, 121 °C heat treatment.

Table 2 Effects of different heat treatment temperatures (70 °C and 121 °C) on the texture characteristics of different varieties of canned lychee pulp[a]

Cultivars		Hardness/N	Elasticity	Cohesiveness	Chewiness
Guiwei	UH 9 d	245 ± 16	0.7 ± 0.2	0.52 ± 0.02	87 ± 8
	HT70 13 d	182 ± 14	0.8 ± 0.3	0.56 ± 0.02	81 ± 8
	HT121 25 d	88 ± 9	0.36 ± 0.05	0.25 ± 0.02	9 ± 2
Nuomici	UH 9 d	217 ± 18	0.6 ± 0.3	0.54 ± 0.03	73 ± 7
	HT70 13 d	184 ± 9	0.45 ± 0.06	0.42 ± 0.02	35 ± 4
	HT121 25 d	98 ± 10	0.33 ± 0.02	0.17 ± 0.02	6 ± 1

[a] UH: unheated; HT70: 70 °C heat treatment; HT121: 121 °C heat treatment. Means ± SDs, $n = 3$.

hydrogen or electrons but also because they have stable radical intermediates.[5,19] Studies have reported that phenolic compounds are closely associated with positive human health outcomes.[20]

The TPC, TFC and antioxidant activity of the UH, HT70 and HT121 canned lychee samples significantly decreased after storage at room temperature for 9 d, 13 d and 25 d, respectively. Studies have reported that when unpeeled canned 'Redhaven' peach fruit was stored at 20 °C for 6 months and when black carrot jams and marmalades were stored at 25 °C for 20 weeks, the TPCs and antioxidant activities were significantly reduced.[21,22] In addition, after storage at room temperature for 6 months, the TPCs of canned pumpkin with sucrose solution and canned pineapple with sucrose solution were reduced by 12.64% and 18.66%, respectively.[23] The TPCs of HT121 canned *Guiwei* and *Nuomici* were significantly higher than those of UH and HT70 samples. Choi reported that the free phenolic content of shiitake (29.0 mg/100 g) increased to 38.3 and 54.6 mg/100 g FW after heat treatment for 15 min and 30 min, respectively, at 121 °C.[12] Phenolic compounds are more easily released because heat treatment breaks the cell walls of plants and increases their extractability.[24,25]

Catechin has eight monomers, including epigallocatechin gallate (EGCG), gallocatechin gallate (GCG), epigallocatechin (EGC), epicatechin (EC), epicatechin gallate (ECG), catechin gallate (CG), catechin (C) and (−)-gallocatechin (GC).[26] (−)-Gallocatechin is one of 8 flavanol catechins. In this study, (−)-gallocatechin was produced during heat treatment at 121 °C, and its content accounted for approximately 89% of the TPC of HT121 canned lychee. Gallocatechin is a proanthocyanidin cleavage product.[27] Lychee pulp contains proanthocyanidins, which may undergo hydrolysis or phloroglucinolysis.[28] The present study measured procyanidin A2 and B2 and found that their contents decreased during heat treatment, which may be related to (−)-gallocatechin generation. Proanthocyanidins are a possible precursor of (−)-gallocatechin. However, proanthocyanidins are complex oligomeric and polymeric flavonoid polymers.[29] The composition of proanthocyanidins in lychee pulp and their changes after thermal processing should be investigated in future research. As expected, (−)-gallocatechin disappeared after storage at room temperature for 25 d. Studies have reported that gallocatechin is unstable during heat treatment[27] and may be more unstable in acidic aqueous systems.[30] The canned lychee pulp was not protected from light, and photolysis reactions may have occurred, during which (−)-gallocatechin would be degraded. Due to the complexity of the lychee pulp matrix, some enzymes may still be active, and enzymatic decomposition reactions may also occur.[31] Phytochemicals with unsaturated covalent bonds are more prone to degradation.[11] In previous studies, a higher content of (−)-gallocatechin was obtained in black tea after hot-air drying. However, after the tea was stored at 20 °C for 6 months, the EGCG, GCG and total catechin contents decreased 28%, 25% and 32%, respectively.[30,32,33] Another group found that after storage at 25 °C for 9 months, the epicatechin and catechin in apple juice were completely degraded.[34] Additionally, vanillic acid and syringic acid were detected in canned *Guiwei* but not in canned *Nuomici*. The food matrix could act as a barrier to the heat effect or induce degradation.[35] Therefore, the composition of phenolic compounds is different in different food matrices.

It has been reported that the reaction mechanism of the FRAP assay is based on electron transfer.[36] However, the ORAC assay is based on hydrogen atom transfer.[37] The differences in the determination of the antioxidant activity by different

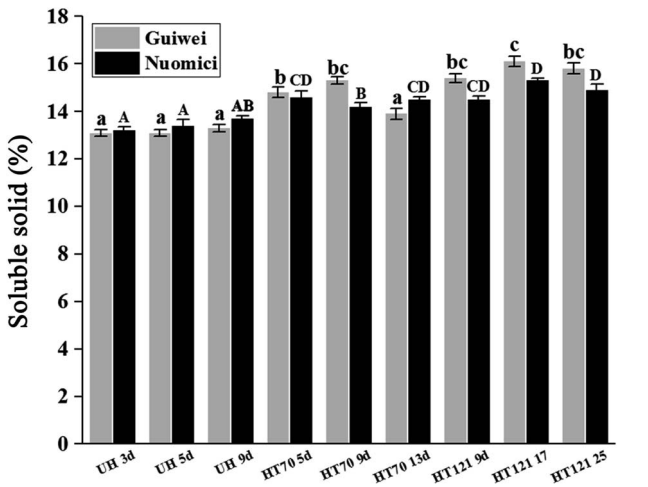

Fig. 5 Effect of the heat treatment temperature (70 °C and 121 °C) on the refractive index of two commercial varieties of canned lychee pulp. Bars labeled with different letters for one variety are significantly different ($p < 0.05$). UH, unheated; HT70, 70 °C heat treatment; and HT121, 121 °C heat treatment.

Table 3 Effects of different heat treatment temperatures (70 °C and 121 °C) on the color of canned lychee pulp determined by CIELAB[a]

Cultivars	L^*	a^*	b^*	ΔE^*
Guiwei UH	29.7 ± 0.4	−0.12 ± 0.02	1.5 ± 0.1	—
Guiwei HT70	30.3 ± 0.5	−0.41 ± 0.02	1.89 ± 0.05	0.71 ± 0.03
Guiwei HT121	25.1 ± 0.2	0.82 ± 0.03	4.0 ± 0.2	5.3 ± 0.2
Nuomici UH	29.4 ± 0.2	0.13 ± 0.01	1.5 ± 0.2	—
Nuomici HT70	30.5 ± 0.6	−0.16 ± 0.01	1.6 ± 0.2	1.2 ± 0.1
Nuomici HT121	25.2 ± 0.2	0.72 ± 0.02	5.4 ± 0.4	5.8 ± 0.3

[a] UH: unheated; HT70: 70 °C heat treatment; HT121: 121 °C heat treatment. Means ± SDs, $n = 3$.

methods are related to the determination principle of the method itself and the structural properties of different antioxidants.[38] The antioxidant activity of canned lychee increased significantly after heat treatment at 121 °C, which was consistent with the results of Chen *et al.*[39] Heat treatment might change the extractability of antioxidant compounds due to the disruption of the plant cell wall, thus releasing the compounds from the insoluble part of lychee pulp and increasing the antioxidant activity.[12] During heat treatment, nonenzymatic reaction products with antioxidant activity, such as melanoidins, formed. Melanoidins are the final products of the Maillard reaction and have different biological activities, including different antioxidant capacities.[40] Therefore, their formation contributed to the increase in the antioxidant activity of lychee pulp during heat treatment.

However, 121 °C heat treatment seriously damaged the texture characteristics and color and significantly increased the soluble solid index of canned lychee. The results of the CIELAB color parameter determination of HT121 and UH canned lychee showed significant differences between these two sample sets. However, there was little difference between the HT70 and UH canned lychee in terms of these characteristics. The heat treatment of canned food damages the cell membrane and leads to cell separation, which decreases food firmness, and the generated phenolic compounds lead to food discoloration. The soluble solid index of canned lychee increased as the thermal processing temperature increased from 70 °C to 121 °C due to the breakdown of the pectin structure upon exposure to high temperatures.[10] These results indicated that heat treatment at high temperature reduces the original quality of fresh lychee and its commercial value.

5. Conclusion

Heat treatment had significant effects on the composition and antioxidant activity of phenolic compounds in canned lychee. The 70 °C heat treatment had less effect on the texture characteristics of lychee pulp than the 121 °C treatment but still increased phenolic compound release and increased antioxidant activity. However, heat treatment at 121 °C had a marked influence on the textural characteristics and color quality of canned lychee. The higher temperature treatment increased the phenolic content and antioxidant activity of canned lychee but also had an adverse effect on the appearance quality and commercial value of canned lychee. Therefore, the 70 °C heat treatment is suitable for canned lychee processing.

Conflicts of interest

There is no conflict of interest.

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