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Green tea polyphenols improved the physicochemical stability of mango powder during storage

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ABSTRACT

In this study, the physiochemical characters including moisture content variation, pH, total soluble solids (TSS), color, ascorbic acid content, total polyphenols, and antioxidant activities of mango powder fortified with green tea polyphenols (GTP) were investigated during storage for 90 d. Our results indicated stable colors of mango powder were found after GTP addition. GTP also inhibited the destruction of ascorbic acid during processing, and decreased its degradation rate during the whole storage. The total polyphenols of mango powder stored at 4 ℃ and room temperature decreased by 37.85% and 51.79%, respectively. After addition with GTP, the total polyphenols decreased only by 7.89%, and 13.31%, respectively. The antioxidant activities rose by 1.6 to 4.6-fold after GTP addition, and it decreased at a slower rate compared to that of unfortified mango powder. Correlation analysis indicated that EGCG might be the main substance that retain the physiochemical stability of mango powder.

Introduction

Mango (*Mangifera indica* L.) is one of the most important economic fruits in Asia and around the world due to its special flavor and nutritional value. According to the Food and Agriculture Organization (FAO) of the United Nations, there are about 100 countries producing mango in 2022, and China's output and cultivation area ranked second in the world (FAO, n.d.). In China, mango is widely distributed in Hainan, Guangxi, Guangdong, Yunnan, Fujian, and Sichuan. Mango is rich in nutrients such as carbohydrate, vitamin C, provitamin A, folate, and so on (Papanikolaou & Fulgoni, 2022). In addition, mango also has abundant bioactive compounds such as carotenes, dietary fiber, and phenolic compounds mangiferin, gallic acid and quercetin (Shah, Patel, Patel, & Parmar, 2010). More and more researches suggest that mango have several pharmacological activities such as anti-oxidant, anti-inflammation, hepatoprotective, antiviral and antitumor (Shah et al., 2010; Ulla et al., 2017). The United States National Health and Nutrition Examination Survey data support that mango consumption is associated with certain health outcomes of human. However, it has been reported that poor post-harvest processing technology was the main factor to limit the consumption of mango (Caparino, Tang, Nindo, Sablani, Powers, & Fellman, 2012). Although the global production of mango is increasing, large amount of mango is spoiled due to the inappropriate storage and processing methods.

Refrigerating, drying, and juice processing were commonly used to preserve mango (Liu et al., 2023). Refrigerating and juice processing need large equipment investment, and the products are not convenient for transportation and long-term storage due to the high moisture content. On the contrary, mango powder is easy to preserve and has good storage stability (Liu et al., 2023). In addition, mango powder can be used for preparing juice, drinks, desserts, baby foods, and confectionaries (Akther, Sultana, Badsha, Rahman, Alim, & Amin, 2020). In this regard, drying mango into powder seems to be a promising approach to reduce post-harvest losses, and increase the shelf-life of the product.

There are several ways to process mango pulp into powder, and freeze-drying, rotary oven drying, cabinet drying, drum drying, spray drying and vacuum drying were widely used (Akther et al., 2020; Caparino et al., 2012). Thermal treatments such as oven drying, drum drying, spray drying may cause significant losses of sensory attributes and nutritional ingredient, especially vitamin C, β-carotenes and polyphenols (Caparino et al., 2012; Liu et al., 2023). In addition, there are several problems associated with spray drying of sugar-rich foods, especially the stickiness of the material make it difficult to splash drying (Bhandari, Datta, & Howes, 1997). Among the techniques commonly used for drying fruits and vegetables, freeze drying is the best method to obtain a high-quality dried product (Marques, Silveira, & Freire, 2006).

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It is worth noting that the freeze-dried mango powder is also easy to be deteriorated under the condition of oxygen and high temperature if there is no antiseptic treatment or special packaging such as nitrogen flush packaging (Caparino et al., 2017). Special packaging is not convenient for general consumers due to the lack of equipment. In order to make full use of the potential health benefits of mango and add value to the commodity, how to improve storage stability of mango powder in a convenient and safe way needs to be studied.

In recent years, green tea polyphenols (GTP) have been reported to have several health benefits including anti-inflammatory, antioxidative, prevention of cancer and cardiovascular diseases, antiviral and neuroprotective effects (Chacko, Thambi, Kuttan, & Nishigaki, 2010). Since GTP are natural, non-toxic, having strong antioxidant activity and health-promoting properties, adding GTP to the diet to improve its quality is of significance. GTP has been used as a natural and healthy additive to preserve a variety of foods including bread, biscuits, beverages, and fresh sponge cakes (Nhung, Chau, Hien, Linh, Ha, & Dong, 2022; Senanayake, 2013). GTP also inhibited the oxidation of various meat products (Papuc, Goran, Predescu, Nicorescu, & Stefan, 2017). Studies were reported that GTP could improve the food stability during storage. For example, stability, antioxidant, and anti-glycation properties of intermediate moisture apple products during storage were improved by fortifying with GTP (Lavelli, Corey, Kerr, & Vantaggi, 2011). In another study, the oxidative stability of biscuits during storage was also improved by GTP (Mildner-Szkudlarz, Zawirska-Wojtasiak, Obuchowski, & Goslinski, 2009). Till now, despite several literatures have compared the effects of different drying methods on the quality of mango powder (Akther et al., 2020; Caparino et al., 2012), few studies have been conducted to evaluate the effect of GTP on the storage stability of mango powder.

Thus, the objective of this study was to investigate the physical character, nutrient, total polyphenols, and antioxidant activity of mango powder fortified with or without GTP during storage. This study will provide important information for the processing of shelf stable, safe, and high-quality mango powder.

Materials and methods

Chemical and reagents

HPLC-grade acetonitrile was purchased from Adamas reagent, Ltd. (Shanghai, China). Vitamin C, 1, 1-diphenyl-2-picrylhydrazyl (DPPH), 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and 2, 3, 5-Triphenyltetrazolium chloride (TPTZ) were purchased from Beijing solarbio science & technology co., Ltd. (Beijing, China). Tea polyphenol standards (C, catechin; CG, catechin gallate; GC, gallocatechin; GCG, gallocatechin gallate; EC, epicatechin; ECG, epicatechin gallate; EGC, epigallocatechin; EGCG, epigallocatechin gallate) were purchased from Shanghai Yuanye Biotechnology Co., Ltd. (Shanghai, China). All other reagents in this study were of analytical grade.

Sample treatment

Fresh mangos (*Mangifera indica* L.) of the cultivar hainan guifei without any mechanical damage were purchased from the local market. Each mango was peeled and cored manually, and then boiled in 100 °C distilled water for 4 min immediately. After that, mango pulps were soaked in 4 °C distilled water to cool, and then drained. Mango pulps were blended to a puree by a high-speed blender (PB40X2-166F, Midea, Foshan, China), and then divided into two groups (control and GTP group) randomly. For the GTP group, GTP was added to the mango puree with the concentration of 180 mg/100 g, which was chosen in order to obtain (per 50 g MP + GTP powder) equivalent amount of GTP that a cup of green tea present and our preliminary experiment. All purees were frozen in the freezer at −80 °C for 24 h, and then freeze-dried in an experimental vacuum lyophilizer (LGJ-10, Shengchao kechuang (Beijing) biotechnology co., LTD., Beijing, China) for 72 h. The dried purees were ground to pass through a 1-mm sieve, and the samples were named as mango powder (MP) and mango powder with GTP (MP + GTP), respectively.

Both MP and MP + GTP samples were sub-divided into six groups, and were packaged with low-density polyethylene bags. Three bags were stored at 4 °C, and another three bags were stored at room temperature (25±2 °C) in a cabinet for three months.

Moisture content

The moisture content was determined according to the British Standards simplified oven drying method (105 °C for 24 h) (BSI, 2009). All the measurements were repeated in triplicate.

pH and total soluble solids (TSS)

1 g of sample was dissolved in 5 mL distilled water. After homogenization for 5 min, the solution was used for pH and TSS measurements. pH was measured by a pH meter (Mettler- Toledo Instruments Co., Ltd., Shanghai, China). Before measurement, the pH meter was calibrated with standard buffer solution (pH 4.01, 6.86, 9.18). TSS was measured using a digital refractometer (ATAGO Co., Ltd., Osaka, Japan).

Color

The color of the mango powder was recorded by a colorimeter (NR60CP, 3nh Technology, Shenzhen, China). Color was expressed in Hunter values (L, a, and b). The total color difference value (△E) was calculated according to Eq. (1).

$$\Delta E = \sqrt{(L^* - L)^2 + (a^* - a)^2 + (b^* - b)^2} \quad (1)$$

where L*, a* and b* are the measured values of the mango powder before storage, and L, a and b are the values of the mango powder during storage.

L-ascorbic acid content

L-ascorbic acid content was measured by the 2,6-dichlorophenolindophenol titration assay according to the method described by Stryjecka *et al.* (Stryjecka, Krochmal-Marczak, Cebulak, & Kiełtyka-Dadasiewicz, 2023). The results were expressed in milligrams per 100 g (mg/100 g).

Sample extracting

The sample was mixed with 80 % methanol (w/v = 1:10) and then ultrasonic extracted at 40 °C for 30 min. After being centrifuged at 12,000 g for 15 min, the supernatant was collected and used for the assays of total polyphenols, antioxidant activities and mass spectrometry.

Total polyphenols

The total polyphenols were measured by the modified Folin-Ciocalteu assay (Fu, Wang, Belwal, Xu, Li, & Luo, 2021), and the result was expressed as milligrams gallic acid equivalent per gram of dry weight (mg GAE/g DW).

Antioxidant activity

The antioxidant activities were determined using DPPH, ABTS and FRAP methods (Tan et al., 2020). L-ascorbic acid (Vc) was used as the standard, and the antioxidant capacity was expressed as milligrams Vc equivalent per gram of dry weight (mg Vc/g DW).

Polyphenol profile by UPLC-QqQ-MS/MS

The tea polyphenol profile was analyzed by an ultra-high pressure liquid chromatograph (UPLC) (Agilent, Santa Clara, California, USA) equipped with an electrospray ionization source (ESI) and a triple quadrupole mass spectrometer (6460QqQ-MS/MS, Agilent). The ZORBAX Eclipse Plus C18 column (100 mm × 2.1 mm i.d., 1.8 μm, Agilent, USA) was used to separate the polyphenol compounds. The mobile phase consisted of a gradient of 0.1 % aqueous formic acid (A) and methanol with 0.1 % formic acid (B) at a flow rate of 0.4 mL/min. The gradient elution was set as follows: 0–11.5 min from 95 % to 5 % A, 11.5–12 min from 5 % to 95 % A, 12–14.5 min with 95 % A. The sample injection volume was 5 μL, and the column temperature was 35 °C.

All the compounds were exactly identified by comparing the dynamic MRM information including retention time, fragmentor voltages, collision energies and transitions with reference standards.

Statistical analysis

All the values were presented as means ± SD. The statistical analyses were performed using the IBM SPSS statistics (version 23.0). Statistically significant differences among the results were analyzed by one-way analysis of variance (ANOVA), followed by Tukey's post hoc test. The correlation was performed in R (x 64, 4.3.1) using the corrplot package.

Results and discussion

Effects of GTP on the moisture content, pH, and TSS of mango powder

Fig. 1A showed the moisture content variation of mango powder with or without GTP after being stored at room temperature or 4 °C for 90 d. The moisture content of mango powder stored at room temperature increased more than 3 %, which was significantly higher than that stored at 4 °C. This was probably because mango powder was easy to absorb moisture at room temperature with the relative high humidity (around 80 %). Our result also indicated that GTP did not change the mango powder hygroscopicity.

The pH (Fig. 1B) of mango powder was fluctuating at the beginning of storage, and significantly decreased after 90 d storage which may be caused by the production of organic acids (Din et al., 2019). In addition, it also might result from the forming of carbonic acid since the sample absorbed carbon dioxide during storage. Falade *et al.* also reported similar result that the pH of sweetened Julie mango juice decreased during storage (Falade, Babalola, Akinyemi, & Ogunlade, 2004). According to our results, the storage temperature and GTP addition had no obvious effect on the pH of mango powder.

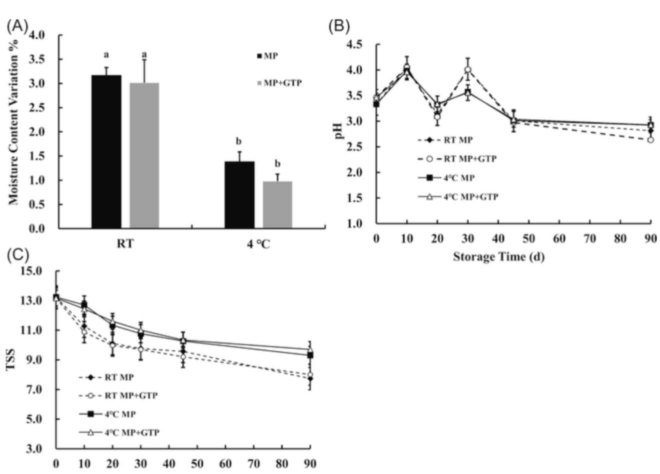

Fig. 1. The moisture content variation (A), pH (B), and TSS (C) of mango powder during storage. Data are expressed as means ± SEM (n = 3). Different letter means significantly different ($P < 0.05$) as determined by one-way analysis of variance (ANOVA), followed by Tukey test.

In addition, the TSS (Fig. 1C) in mango powder was also decreasing, which may be result from the increase of moisture content. In addition, degradation of sugars, vitamins, and pigments may also lead to the decrease of TSS. Similar result was also found in the dried carrot slices during storage (Sra, Sandhu, & Ahluwalia, 2014). Falade et al. also reported in previous study that about 10 % of soluble solids of mango juice were decreased after 12 weeks of storage (Falade et al., 2004). Obviously, the TSS in the mango powder which was stored at 4 °C was higher than that stored at room temperature no matter whether GTP was added or not. Anyway, GTP addition had no obvious effect on the TSS of mango powder.

Color variation of mango powder during storage

Lightness and yellowness are two important parameters of mango powder. Before storage, the L* value of MP + GTP was lower than that of MP, and the a* value was higher than that of MP (Table 1). This difference comes from the brown or reddish-brown color of GTP. During storage, the L* and b* values of mango powder decreased, and the a* value increased with the time increasing. This result indicated the brightness of mango powder gradually decreased, and the color changed toward more and more brown. The lightness change may result from the variation in moisture content since the less water, the higher transmittance. In addition, change in color might derive from the non-enzymatic maillard reactions during storage since our samples were blanched. As reported by previous literatures, similar browning reactions were also found in the intermediate moisture apple and raisins products (Gulec, Kundakci, & Ergonul, 2009; Lavelli et al., 2011).

According to the ΔE value, the color variation of mango powder stored at 4 °C was significantly smaller than that stored at RT. Similarly, Giovanelli et al. also reported that the color variation of intermediate moisture tomato and dried tomato products stored at lower temperatures (4 °C) were much lower than those stored at 20, and 37 °C (Giovanelli & Paradiso, 2002). Interestingly, the ΔE value of MP + GTP was significantly lower than that of MP no matter it was stored at RT or 4 °C. These results indicated that the browning rates were different between MP and MP + GTP samples. GTP has been reported to reduce the extend of Maillard reaction in glucose-glycine model system and GTP-fortified apple product (Lavelli et al., 2011; Noda & Peterson, 2007). Our results indicated GTP might inhibit the Maillard reaction of mango powder, and improved the color stability.

L-ascorbic acid content variation of mango powder during storage

Ascorbic acid is one of the major nutrients in mango products. As shown in Fig. 2., the ascorbic acid content in MP + GTP was significantly higher than those in MP at the begging of storage. The result could be explained as the reducibility of tea polyphenols will interfere with the titration result, resulting in a false large value. In addition, ascorbic acid might be degraded during the powder processing and GTP partly preserved ascorbic acid from oxidation. Literature data demonstrated that significant losses in ascorbic acid occur during mango drying, intermediate moisture tomato and *Brassica parachinensis* processing, and so on (Cao, Zhang, Mujumdar, Xiao, & Sun, 2007; Giovanelli et al., 2002; Sogi, Siddiq, & Dolan, 2015).

The ascorbic acid content decreased significantly during storage interval. It decreased from 45.40 to 41.04 and 32.45 mg/100 g for MP + GTP stored at 4 °C and RT, respectively. At the same time, it decreased from 30.87 to 20.9 and 10.62 mg/100 g for MP stored at 4 °C and RT, respectively. Loss of ascorbic acid in mango powder could be due to aerobic and anaerobic reactions, as reported in the study of chemical stability of dried mango powder during storage (Caparino et al., 2017). Similar trend of ascorbic acid degradation was also reported in several

Table 1
Changes in color parameters L*, a*, b*, ΔE of mango powder during storage. Data are expressed as means ± SEM (n = 3). Different letter means significantly different ($P < 0.05$) as determined by one-way analysis of variance (ANOVA), followed by Tukey test.

	Sample	L*	a*	b*	ΔE
0d	MP	85.64 ±0.08^{a}	0.54 ±0.02^{b}	30.41 ±0.13^{a}	\
	MP + GTP	84.58 ±0.11^{b}	1.74 ±0.07^{a}	30.11 ±0.23^{a}	\
10d	MP (RT)	84.89 ±0.06^{a}	1.43 ±0.05^{c}	30.06 ±0.34^{a}	1.30±0.17^{b}
	MP + GTP (RT)	83.55 ±0.19^{c}	2.05 ±0.02^{a}	28.46 ±0.26^{b}	1.99±0.25^{a}
	MP (4 °C)	84.43 ±0.18^{b}	1.20 ±0.03^{d}	30.53 ±0.26^{a}	1.44±0.17^{b}
	MP + GTP (4 °C)	84.17 ±0.03^{b}	1.79 ±0.05^{b}	30.10 ±0.12^{a}	0.45±0.05^{c}
20d	MP (RT)	83.91 ±0.25^{a}	2.26 ±0.08^{a}	29.12 ±0.60^{a}	2.91±0.14^{a}
	MP + GTP (RT)	83.35 ±0.08^{b}	2.11 ±0.15^{ab}	27.72 ±0.10^{b}	2.73±0.07^{a}
	MP (4 °C)	84.20 ±0.03^{a}	1.87 ±0.06^{bc}	29.99 ±0.20^{a}	2.02±0.08^{b}
	MP + GTP (4 °C)	84.03 ±0.08^{a}	1.81 ±0.02^{c}	29.98 ±0.39^{a}	0.78±0.12c
30d	MP (RT)	83.23 ±0.06^{b}	2.41 ±0.21^{a}	25.99 ±0.49^{c}	5.39±0.42^{a}
	MP + GTP (RT)	83.04 ±0.03^{b}	2.59 ±0.07^{a}	27.23 ±0.17^{b}	3.38±0.15^{b}
	MP (4 °C)	83.80 ±0.13^{a}	2.15 ±0.17^{ab}	30.82 ±0.38^{a}	2.55±0.15^{c}
	MP + GTP (4 °C)	83.87 ±0.10^{a}	1.92 ±0.05^{b}	29.81 ±0.08^{a}	0.81±0.05^{d}
45d	MP (RT)	81.16 ±0.20^{ab}	2.98 ±0.09^{a}	25.05 ±0.03^{d}	7.40±0.16^{a}
	MP + GTP (RT)	79.93 ±0.04^{c}	2.92 ±0.05^{a}	26.50 ±0.13^{c}	6.01±0.08^{b}
	MP (4 °C)	80.66 ±0.36^{b}	2.77 ±0.06^{a}	30.08 ±0.09^{a}	5.47±0.35^{c}
	MP + GTP (4 °C)	81.44 ±0.08^{a}	2.15 ±0.08^{b}	29.21 ±0.07^{b}	3.30±0.08^{d}
90d	MP (RT)	77.62 ±0.73^{bc}	4.09 ±0.11^{a}	23.17 ±0.24^{d}	11.41 ± 0.44^{a}
	MP + GTP (RT)	78.26 ±0.15^{ab}	3.49 ±0.13^{b}	25.77 ±0.25^{c}	7.87±0.10^{c}
	MP (4 °C)	76.75 ±0.50^{c}	2.86 ±0.02^{c}	26.92 ±0.47^{b}	9.84 ± 0.61^{b}
	MP + GTP (4 °C)	79.51 ± 0.31^{a}	2.78 ± 0.03^{c}	28.85 ± 0.05^{a}	5.33 ± 0.29^{d}

commercial fruit juices (Kabasakalis, Siopidou, & Moshatou, 2000) and vegetable powders (Farooq et al., 2020). Obviously, GTP significantly decreased the ascorbic acid content loss during storage, which might be explained as tea polyphenols competitively inhibited the oxidation of ascorbic acid, or improved the stability by interaction. Similarly, as reported by Zhang et al., the ascorbic acid content of jujubes could be maintained during ambient temperature storage if 1–3 g/L tea polyphenols were coated (Zhang, Li, Dong, Zhi, & Zong, 2016). According to Chen et al., tea polyphenols also decreased the loss of ascorbic acid during cold storage of litchi fruit (Chen, Zhang, Shen, Duan, & Jiang, 2014). In addition, our result also confirmed that compared to RT, 4 °C is benefit for the maintenance of ascorbic acid since ascorbic acid is a heat sensitive compound and its destruction increases as the temperature of dried products increases (Caparino et al., 2017). In all, this result indicated that the content and stability of ascorbic acid in MP + GTP powder was superior compared to that in MP powder.

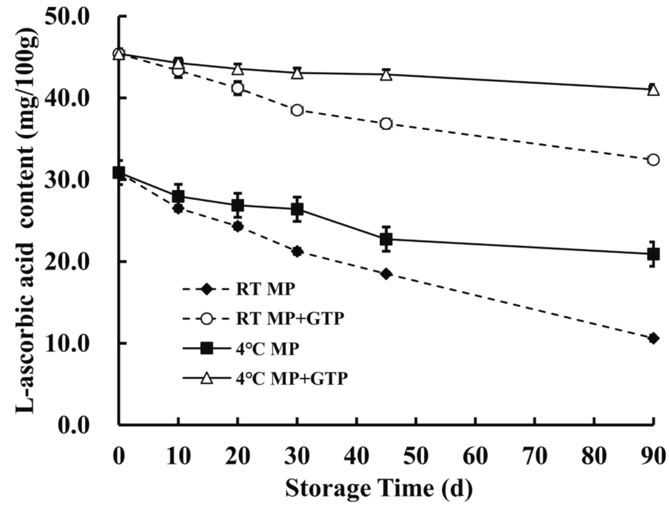

Fig. 2. The L-ascorbic acid content variation of mango powder during storage. Data are expressed as means ± SEM (n = 3).

Total polyphenols variation of mango powder during storage

The total polyphenols variation was shown in Fig. 3A. Before storage, the total polyphenols in MP and MP + GTP were 5.02 and 12.92 mg GAE/g DW, respectively. This result was consistent with previous reports that the total polyphenols of mango fruits ranged from 8.71 to 193.36 mg/100 g fresh weight (Ma et al., 2011). Therefore, mango powder could also be considered as a good source of phenolic compounds. Obviously, the higher content in MP + GTP came from the addition of tea polyphenols. After storage for 90 d, it decreased to 11.90 and 11.20 mg GAE/g DW for MP + GTP samples stored at 4 °C and RT, respectively. For MP samples stored at 4 °C and RT, it decreased to 3.12 and 2.42 mg GAE/g DW. These results indicated low temperature (4 °C) inhibited the degradation of phenolic compounds in mango powder, and the loss of total polyphenols in MP + GTP samples were decreased compared to that in MP during storage which might because tea polyphenols were more stable than those phenolic compounds in mango powder. Similar result was also found by Lavelli et al. who reported that the degradation rate of total phenolics in green tea-fortified apple product was much lower than that in normal apple product (Lavelli et al., 2011). It was worth noting that sugars, proteins, and ascorbic acid

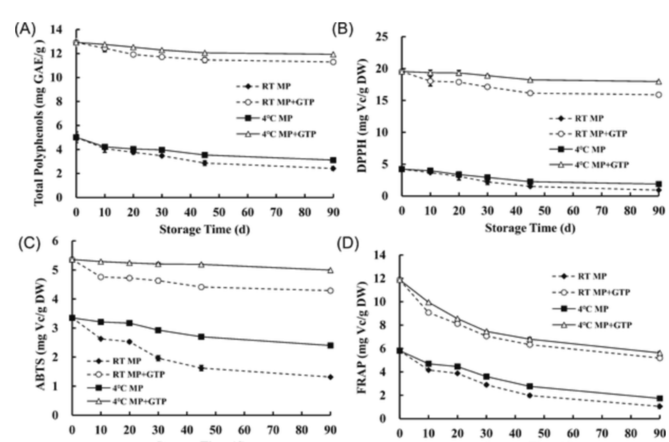

Fig. 3. The total polyphenols contents (A), DPPH (B), ABTS (C), and FRAP (D) variation of mango powder during storage. Data are expressed as mean ± SEM (n = 3).

would influence the reaction resulting in an overestimation of the total polyphenols content (Tappi, Tylewicz, Romani, Dalla Rosa, Rizzi, & Rocculi, 2017; Walker, Everette, Bryant, Green, Abbey, & Wangila, 2009).

Antioxidant activities variation of mango powder during storage

The antioxidant activities of mango powder as determined by DPPH, ABTS, and FRAP methods were shown in Fig. 3 (B-D). The DPPH scavenging activity decreased by 8.03, 18.63, 55.21, and 78.12 % in the sample of MP + GTP (4 °C), MP + GTP (RT), MP (4 °C), and MP (RT), respectively. The ABTS scavenging activity decreased by 6.81, 19.98, 28.33, and 60.79 % in the sample of MP + GTP (4 °C), MP + GTP (RT), MP (4 °C), and MP (RT), respectively. In general, the trend of DPPH and ABTS changes during storage were consistent with those of ascorbic acid and total polyphenols. As shown in Fig. 4., the correlation analysis indicated that DPPH and ABTS were significantly correlated with ascorbic acid and total polyphenols. Indeed, the positive correlations between total polyphenols and DPPH or ABTS have been confirmed in several literatures (Huang, Zhu, Fu, Zou, Li, & Luo, 2022; Ma et al., 2011). The reducing power ability (FRAP) of mango powder decreased by 52.60, 56.40, 70.22, and 81.99 % in the sample of MP + GTP (4 °C), MP + GTP (RT), MP (4 °C), and MP (RT), respectively. By comparison, the decrease of FRAP was higher than the DPPH and ABTS scavenging activities. It might because FRAP assay detects not only antioxidants but also all other compounds which have reducing ability such as reducing sugar, metal ions, and so on (Benzie & Strain, 1996).

Consistent with the above result of total polyphenols, this result also indicated that compared to RT, 4 °C was benefit for the stability of antioxidant activity, and the loss of antioxidant activity of mango powder decreased after adding GTP. As we all know, GTP has strong antioxidant activity (Senanayake, 2013), therefore, the antioxidant activity of mango powder was significantly increased with the addition of GTP. According to Dai et al.(Dai, Chen, & Zhou, 2008), green tea polyphenols and ascorbic acid showed synergistic antioxidant, which may explain why GTP addition markedly maintained relatively high levels of radical scavenging activities of mango powder after 90 days of storage. Similarly, as reported by Lavelli et al., antioxidant activity loss of the intermediate moisture apple powder was significantly inhibited after fortified with green tea (Lavelli et al., 2011).

Phenolic composition of mango powder fortified with GTP

To understand the phenolic profile of GTP and its variation during the storage, UPLC-QqQ-MS/MS was used to identify and quantify the phenolic substances of MP + GTP. As shown in Table 2, eight phenolic compounds including catechin (C), catechin gallate (CG), gallocatechin (GC), gallocatechin gallate (GCG), epicatechin (EC), epicatechin gallate (ECG), epigallocatechin (EGC) and epigallocatechin gallate (EGCG) were detected, and EGCG was the most abundant phenolic compound in green tea. This result was consistent with the literatures (Senanayake, 2013). GTP was rich in phenolics, which had been reported to have strong antioxidant activities, even stronger than ascorbic acid and vitamin E (Chen et al., 2014). Therefore, it was suggested that the strong antioxidant activity of those phenolics could be responsible for the high antioxidant activity of MP + GTP. Expectedly, each compound decreased with the storage time increased, and the one stored at 4 °C was higher than that stored at RT at the same timepoint. It also can be seen that the degradation rate of each phenolic compound was higher than that of the total polyphenols. This may be because the results of total polyphenols may be interfered by sugars, proteins, and so on. Similar result has been reported by Lavelli *et al.* that the half-life of total polyphenols was much longer than the individual phenolic compounds in the green tea fortified apple products (Lavelli et al., 2011).

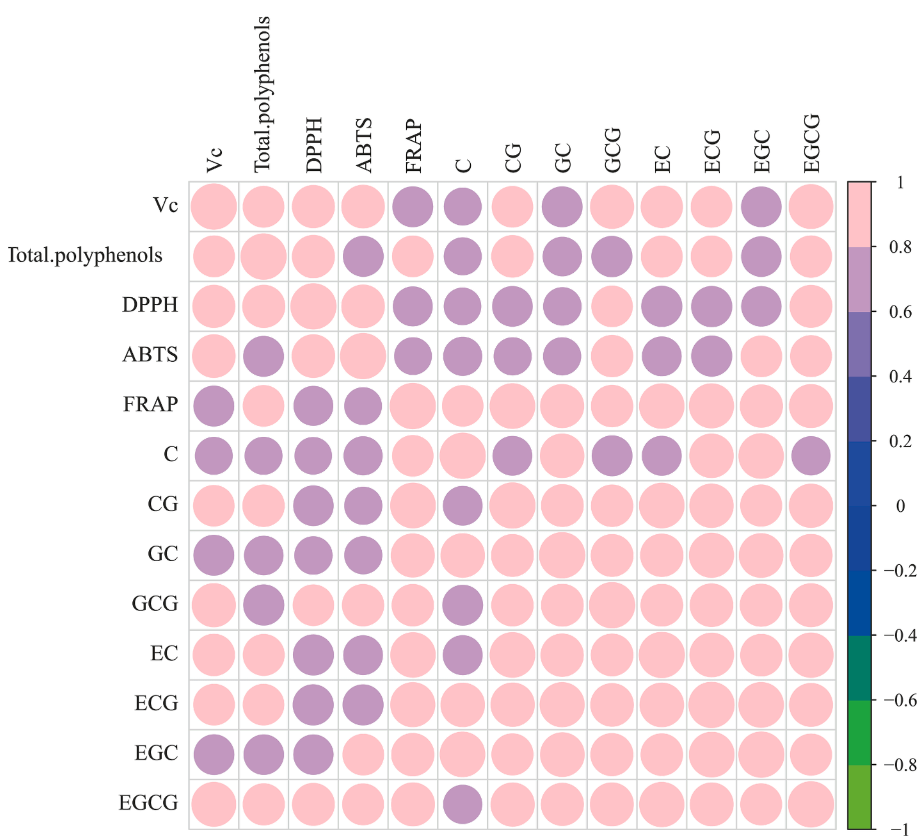

Fig. 4. Correlation plots among ascorbic acid, total polyphenols, antioxidant activity, and phenolic compounds. C, catechin; CG, catechin gallate; GC, gallocatechin; GCG, gallocatechin gallate; EC, epicatechin; ECG, epicatechin gallate; EGC, epigallocatechin; EGCG, epigallocatechin gallate.

Table 2
Changes in phenolic substances of mango powder during storage. Data are expressed as means ± SEM (n = 3). Different letter among the samples at the same storage condition means significantly different ($P < 0.05$) as determined by one-way analysis of variance (ANOVA), followed by Tukey test. C, catechin; CG, catechin gallate; GC, gallocatechin; GCG, gallocatechin gallate; EC, epicatechin; ECG, epicatechin gallate; EGC, epigallocatechin; EGCG, epigallocatechin gallate.

	Samples	C (mg/kg, DW)	CG (mg/kg, DW)	GC (mg/kg, DW)	GCG (mg/kg, DW)	EC (mg/kg, DW)	ECG (mg/kg, DW)	EGC (mg/kg, DW)	EGCG (mg/kg, DW)
0d	MP + GTP	118.91 ± 0.49^{a}	296.50 ± 5.16^{a}	473.85±2.97^{a}	1341.84±11.62^{a}	488.38±1.82^{a}	1555.24 ±14.91^{a}	2139.98 ±23.62^{a}	8651.17 ±179.82^{a}
10d	RT MP + GTP	61.32±0.18^{b}	234.21±7.90^{b}	315.90±8.24^{b}	1251.75 ±14.08^{ab}	391.15±2.93^{b}	996.75±4.31^{b}	1298.45±3.55^{b}	7279.22±68.30^{b}
	4℃ MP + GTP	70.54±0.39^{b}	247.98±6.81^{b}	311.81±1.15^{b}	1280.22±4.67^{ab}	444.33 ±12.11^{b}	1166.76 ±18.37^{b}	1558.37 ±14.25^{b}	7933.22±51.13^{b}
20d	RT MP + GTP	55.97±1.04^{c}	155.77±3.07^{c}	301.87±6.48^{b}	1152.08 ±68.01^{bc}	371.22±1.22^{c}	874.28±11.62^{c}	1183.16±3.06^{b}	7076.09±4.99^{b}
	4℃ MP + GTP	69.21±0.08^{b}	218.93 ±17.93^{b}	311.32±3.57^{b}	1221.19 ±36.85^{bc}	417.66±3.17^{c}	1078.59 ±16.70^{b}	1436.96±8.41^{c}	7776.72±5.39^{b}
45d	RT MP + GTP	56.41±1.57^{c}	106.65±2.10^{d}	268.76±6.12^{c}	1115.55±38.19^{cd}	302.68±1.05^{d}	766.14±16.88^{d}	1116.45 ±10.58^{d}	5509.88±109.46^{c}
	4℃ MP + GTP	64.46±0.48^{c}	134.63±6.00^{c}	280.69 ±18.70^{bc}	1216.62±7.84^{bc}	347.29±3.58^{d}	931.89±1.67^{c}	1401.53 ±12.74^{c}	6838.52±37.36^{c}
90d	RT MP + GTP	44.69±0.04^{d}	59.61±8.36^{e}	171.05±2.18^{d}	1009.92±9.30^{d}	229.36±0.46^{e}	590.97±8.60^{e}	938.47±10.25^{e}	3652.16±70.10d
	4℃ MP + GTP	63.98±1.32^{c}	72.31±10.82^{d}	252.35±3.46^{c}	1174.84±4.28^{c}	256.07±1.50^{e}	765.20±46.68^{d}	1220.45 ±17.93^{d}	5580.75 ±244.94^{d}

In order to elucidate the main effective substances in tea polyphenols, correlation analysis was carried out, and the results indicated that EGCG was highly correlated with total polyphenols and antioxidant activities. EGCG is the most abundant catechin in green tea, and have the most potent pharmacological activity (Xing, Zhang, Qi, Tsao, & Mine, 2019). As reported by Boulmokh *et al.* (Boulmokh, Belguidoum, Meddour, & Amira-Guebailia, 2021), EGCG showed higher antioxidant activities than epicatechin and resveratrol, and the most preferential sites were gallate moiety and 4 '–OH in EGCG. Therefore, the increase of antioxidant activity and superior stability of mango powder may be attributed to the antioxidant activity of EGCG.

Conclusion

GTP has no obvious effect on the moisture content, pH, and TSS, but significantly improved the color stability and increased the ascorbic acid content of mango powder. In addition, the decrease of total polyphenols and antioxidant activities of mango powder were inhibited by GTP. EGCG would be the main effective compound in GTP. Our results indicated green tea polyphenols addition improved the stability, enhanced the nutritional attributes of mango powder, and could be a valuable way of making innovative mango products.

CRediT authorship contribution statement

Si TAN: Conceptualization, Methodology, Investigation, Writing – original draft, Funding acquisition. **Guangzhen XIN:** Investigation, Writing – review & editing. **Ruobing XIE:** Investigation, Writing – review & editing. **Xiaowen WU:** Investigation, Writing – review & editing. **Wenfeng LI:** Formal analysis, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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