Application of tea polyphenols in combination with 6-gingerol on shrimp paste of during storage: biogenic amines formation and quality determination

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Tea polyphenols (TP) have shown antioxidant activity and antimicrobial properties in the food industry. Assessment of anti-oxidation potential of 6-gingerol (GR) has also been verified. As little is known about the use of tea polyphenols either individually or in combination with 6-gingerol in shrimp paste, we aimed to investigate the effect of tea polyphenols combined with 6-gingerol on the biogenic amines inhibition and quality of shrimp paste stored at 25°C for 160 days. The shrimp paste samples were assigned into four groups: (1) control; (2) tea polyphenols treatment (0.3%); (3) 6-gingerol treatment (0.3%); (4) tea polyphenols (0.15%) + 6-gingerol (0.15%). Samples with no addition were used as control. The results indicate that treatment with tea polyphenols + 6-gingerol (TPGR) maintained paste appearance, inhibited oxidation of protein and lipids, and reduced microorganism counts compared to control treatment. The efficiency was superior to that of tea polyphenols or 6-gingerol treatment. Furthermore, shrimp paste treated with TPGR also exhibited significantly higher inhibition of biogenic amines. Total amino acids determination proved the efficacy of TPGR by maintaining the more amino acids of shrimp paste during ambient temperature storage. Our study suggests that TPGR might be a promising candidate for fermented foods due to its synergistic effect to maintain products quality and extending their shelf-life.

Keywords: tea polyphenols, 6-gingerol, shrimp paste, biogenic amine, quality

Introduction

Shrimp fermentation is one of the most common methods of shrimp preservation in Asia countries due to the simplicity of technology and low cost of equipment. Shrimp paste is one of the most popular products in the eastern coastal areas of China due to its salty, rich seafood flavor and characteristic appetite-stimulating aroma. Shrimp paste is traditionally obtained through the natural fermentation process of whole shrimp in the presence of salt (25–30% on the weight basis) under ambient conditions. Although the traditional shrimp paste is insusceptible to contamination by microorganisms and has long shelf life of 6 months under

Citation:
Cai L, Liu S, Sun L, Wang Y, Ji H and Li J (2015) Application of tea polyphenols in combination with 6-gingerol on shrimp paste of during storage: biogenic amines formation and quality determination. Front. Microbiol. 6:981. doi: 10.3389/fmicb.2015.00981
room temperature conditions, it is usually used as condiments
due to its high concentration of salt. Low-salt shrimp paste is
also obtained by the fermentation with small shrimp used as raw
materials. It satisfies the public demands for healthy food owing
to its high moisture and low salinity (≤18%), while lower salinity
may decrease the antimicrobial capacity and thus affecting the
quality of products stored at room temperature, resulting in short
shelf life of about 100 days. The short shelf life of low-salt shrimp
paste is an impediment to the distribution and marketing of the
room temperature products. Thus, prolonging the storage period,
while preserving their quality, would benefit the shrimp paste
industry as well as consumers.

Several recent studies have focused on using natural
ingredients to enhance products quality during storage (Feng
et al., 2012; Li et al., 2013; Cai et al., 2014, 2015a). Tea
polyphenols (TP) have shown antioxidant activity and non-
toxicity in the food industry. TP has also been proved to be
effective against cancer and cardiovascular disease. Thus, TP
has beneficial prospects for its use as antioxidants (Kuriyama
et al., 2006; Pasrija et al., 2015). The antioxidant mechanism
of polyphenols is mainly due to their capacity in scavenging
reactive oxygen radicals and chelating metal ions (Dangles, 2012;
Afzal et al., 2015). Additionally, tea polyphenols also possess
antimicrobial properties (Chinnathambi and Alharbi, 2013).
Ginger (Zingiber officinale Roscoe) is one of the commonly used
spices belonging to the Zingiberaceae family and widely used
in processed food, such as chutneys, jams, pickles, beverages
and bakery products, as well as in other industrial sectors. It is
regularly used as seasonings to enhance the sensory quality of
food. Besides researching its health benefits (Shariatpanahi et al.,
2010), phytochemicals obtained in ginger and their antimicrobial
activities against some microorganisms were also investigated. 6-
Gingerol (GR) extracted from rhizome of the ginger is reported
to possess various bioactive properties such as anticancer, anti-
inflammation, antimicrobial, and anti-oxidation (Singh et al.,
2008; Baliga et al., 2012; Yusof et al., 2015). In particular, 6-
gingerol could reduce bacterial biofilm formation and virulence
via quorum sensing inhibition (Kim et al., 2015). Assessment
of anti-oxidation potential of 6-gingerol has also been verified,
which makes it important to apply it in pharmaceutical,
agronomic, and food industries, as food preservers and additives
and as natural remedies (Jeena et al., 2014).

However, to our knowledge, the use of tea polyphenols either
individually or in combination with 6-gingerol, has not been
studied to date, in shrimp paste. Thus, the objective of the
present study was to determine the effect of tea polyphenols and
6-gingerol, applied individually and/or in combination, on
quality of shrimp paste during room temperature storage, to
further understand the roles of tea polyphenols and 6-gingerol
as antioxidants and antimicrobials during the storage of shrimp
paste.

**Materials and Methods**

**Samples Treatment and Chemicals**

The shrimp (Acetes spp.) was cleaned and filtered with a layer
of nylon screen. The washed shrimp was filtered, followed
by coarse grinding using basket centrifuge and autoclave at
115°C for 10 min. The starter was prepared by fermenting the
mixture of flour (10%, w/w) and starter culture (0.1%, w/w)
and distilled water (10%, w/w) at 32°C for 20 h. To exhibit the
characteristic and amazing taste of shrimp paste, the mixture
was fermented by adding salt (18%, w/w) at 42°C for 30 d. The
paste was grinded by colloid mill and sterilized at 121°C for
15 min. In a preliminary experiment, we measured a series of
concentrations of both additions, including tea polyphenols and
6-gingerol, that is, 0.2, 0.3, 0.4, and 0.5%. All natural ingredients
at the concentration of 0.2 or 0.3% significantly inhibited paste
spoilage, and 0.3% had the preferable effect. However, 0.4 or
0.5% of treatment caused some sensory damages, including
off-flavor or discoloration in the shrimp paste. Therefore, a
concentration of 0.3% was chosen to use in this experiment.
The Shrimp paste samples were randomly assigned into four
groups: (1) control; (2) tea polyphenols treatment (0.3%); (3)
6-gingerol treatment (0.3%); (4) tea polyphenols (0.15%) +
6-gingerol (0.15%). Samples with no addition were used as
control.

After that, they were agitated by a magnetic stirrer for
10 min. For each group, 30 pieces of shrimp paste were used.
Then, the shrimp paste samples were stored at 25 ± 1°C
for subsequent quality assessment. Physicochemical, biogenic
amines, microbiological and sensory analyses were performed
at 40-day intervals to determine the quality of shrimp paste.

**Color Measurement**

The color of shrimp paste samples (10 g) were measured with
a WSC-S colorimeter (Shanghai Precision Instrument Co. Ltd.,
Shanghai, China). Data collected included color coordinates
lightness values (L*), a* values (red-green scale) and b* values
(yellow-blue scale). The color intensity is expressed by the
chroma value (C*ab), while hue (H*ab) represents the purity
of color, were respectively calculated according to the formula:
C*ab = (a*²+b*²)1/2 and H*ab = arctan (a*/b*).

**Total Volatile Basic Nitrogen (TVB-N)**

The TVB-N values were determined as described by
Ozogul and Balikci (2013) with a Kjeltec 8400 (Foss, Sweden) using
steam distillation for extraction volatile bases from shrimp paste
samples. Briefly, 10 g of shrimp paste was homogenized with
50 mL of distilled water on a Kjeldahl distillation tube. After
homogenization, 3 mL of silicone anti-foaming agent and 1 g of
MgO were added. The distillate was collected into 10 mL of 0.1 M
hydrochloric acid solution with an indicator solution (methyl
red). Steam distillation process was ended after check with a
pH strip for the complete absence of alkalinity on the distillate.
The distillate was titrated with 0.0167 M sodium hydroxide
solution, and the results were expressed in mg nitrogen per 100 g
sample.
Thiobarbituric Acid Reactive Substances (TBARS)

In this study, the TBA value of shrimp paste samples was evaluated by measuring the concentration of malonaldehyde (Botsoglou et al., 1994) with some modification. Samples (200 mg) were homogenized with 4.8 mL of a 5% solution of potassium chloride. To 0.5 mL of homogenate, 3 mL of 1% phosphoric acid and 1 mL of 0.6% TBA aqueous solution were added. The mixture was incubated in boiling water for 90 min followed by an ice bath for 10 min. Then 4 mL of 1-butanol was added. The tubes were shaken and the supernatant was removed after centrifugation. The absorbance (As) of the resulting pigment was recorded at 532 nm using a UV-Vis spectrophotometer (UV-2550, Shimadzu). A reagent blank was run and the absorbance (Ab) recorded. The absorbance values were converted to the TBA value (mg of malonaldehyde equivalents/kg of tissue) using Equation (1):

\[ \text{TBA} = 50 \times \frac{(A - Ab)}{200} \]  

Total Amino Acids Composition

The total amino acids contents were determined using a full-automatic amino acid analyzer (L-8900A, Hitachi, Tokyo, Japan). An appropriate pretreatment for the samples was necessary before amino acids analysis, according to the method proposed by Kim et al. (2003) with some modifications. Samples (10 mg) were hydrolyzed in 6 M HCl in evacuated sealed tubes at 110°C for 24 h. A calibration curve was obtained with standard amino acid mixture (Sigma, St. Louis, MO, USA) and qualitative analysis was made on the basis of retention time and peak area of standard compounds.

Microbiological Analyses

Shrimp paste samples (10 g) were diluted with phosphate buffer (3.4% v/v, pH 7.2) in sterile containers to an initial dilution of 1:10. Additional serial dilutions were performed when needed. Total viable counts (TVC) was determined on plate count agar (PCA, Aoboxing Bio-Tech, Beijing, China) by counting the number of colony-forming units after incubation at 35°C for 48 h. Three replicates were made for each sample and four appropriate dilutions were used for each replicate. Microbiological data were transformed into logarithms of the number of colony forming units (CFU/g).

Biogenic Amines

BAs of all samples were determined according to the methods described by Park et al. (2010). Briefly, 5 g of each sample were homogenized with 20 ml 0.1 M hydrochloric acid using a homogenizer for 1 min. The homogenate was centrifuged at 11,190 g for 15 min, and the supernatant was collected. The residue was extracted again with 20 ml 0.1 M hydrochloric acid. The supernatants were then combined and adjusted to 50 ml with 0.1 M hydrochloric acid. A stock of standard solution was prepared by adding an accurately weighed amount of each amine (100 mg) to a 100 mL volumetric flask and brought to the mark with 0.1 M HCl. The standard solutions were stored at 4°C until use. Each extracted sample or standard solution (0.3 ml) was mixed with 0.05 ml of saturated NaHCO₃ and 0.05 ml of 2 M NaOH. 0.3 ml of 10 mg/ml DNS-Cl solution prepared in acetone was added and the reaction mixture was incubated at 45°C for 1 h in darkness. Residual DNS-Cl was removed by adding 0.02 ml 25% ammonia. After 30 min the mixture was adjusted to 1.0 mL with acetonitrile and centrifuged at 2417 g for 10 min. The supernatant was filtered through 0.22-μm filters prior to HPLC analysis.

Sensory Evaluation

Sensory evaluation of shrimp paste (10 g) was performed by an 8 trained panel using the structured scaling test. Panel development followed the prescreening, screening, training, and performance evaluation phases as described previously (Cross et al., 1978). Panelists scored for color, aroma, flavor and juiciness of shrimp paste according to a 9-point hedonic scale (9—like extremely to 1—dislike extremely). A sensory score of 4 was taken as the borderline of acceptability.

Statistical Analysis

The experiment followed a completely randomized design (n = 3). Data were subjected to One-Way analysis of variance (ANOVA). Mean separations were assessed by Duncan’s multiple range test (SAS Version 8.1). Differences at p < 0.05 were considered significant.

Results and Discussion

Effect of Tea Polyphenols in Combination with 6-gingerol Treatment on Color

The appearance of food products is of major importance to consumers, both from the point of view of acceptability and of preference. So, color plays a crucial role when evaluating the quality of the shrimp paste at the point of sale. Different values obtained after application of TPGR, compared to the control treatment, are shown in Table 1. From this table, the L* values of control samples significantly (p < 0.05) decreased after 40 days, and it was 41.77 at day 80 and 38.64 at day 120; higher L* values were observed in TPGR samples compared to control after 40 days; the TPGR samples were higher than the TP or GR samples in L* values, mainly attributed to the inhibition of 6-gingerol on melanosis formation in shrimp paste and also the synergistic effect of TP combined with GR treatment (Stoilova et al., 2007; Nile and Park, 2015). The values of b* decreased from day 0 to day 160, indicating an evolution toward gray tones as the storage time, and the similar decreasing trend was found in the values of a*. Regarding parameters C*ab and H*ab, no significant differences were observed in TPGR samples compared to TP or GR samples in the present study.
### Table 1 | Changes in color of shrimp paste treated with tea polyphenols + 6-gingerol stored at 25°C for 160 days.

| Treatments       | L*         | a*         | b*         | C*ab       | H°ab       |
|------------------|------------|------------|------------|------------|------------|
| **0 DAYS**       |            |            |            |            |            |
| Control          | 48.50 ± 0.16aA | 2.74 ± 0.10aA | 17.51 ± 0.85aA | 17.72 ± 0.85aA | 0.16 ± 0.01aA |
| TP               | 48.37 ± 0.63aA | 2.61 ± 0.12aA | 17.77 ± 0.54aA | 17.96 ± 0.55aA | 0.15 ± 0.01aA |
| GR               | 47.25 ± 0.47aA | 2.64 ± 0.19aA | 17.67 ± 0.61aA | 17.87 ± 0.64aA | 0.15 ± 0.01aA |
| TPGR             | 47.10 ± 1.20aA | 2.78 ± 0.06aA | 17.72 ± 0.55aA | 17.94 ± 0.56aA | 0.16 ± 0.01aA |
| **40 DAYS**      |            |            |            |            |            |
| Control          | 44.48 ± 0.84bA | 2.29 ± 0.16bB | 16.31 ± 0.91aB | 16.47 ± 0.92aB | 0.14 ± 0.01aA |
| TP               | 44.97 ± 0.68bAB | 2.36 ± 0.10abAB | 17.10 ± 0.46abAB | 17.26 ± 0.47abAB | 0.14 ± 0.01aA |
| GR               | 44.94 ± 0.80abAB | 2.42 ± 0.10abAB | 17.34 ± 1.31aA | 17.51 ± 1.32aAB | 0.14 ± 0.01aA |
| TPGR             | 46.57 ± 1.10aAB | 2.57 ± 0.14aA | 17.47 ± 0.15aA | 17.66 ± 0.20aAB | 0.15 ± 0.01aA |
| **80 DAYS**      |            |            |            |            |            |
| Control          | 41.77 ± 1.04bB | 1.62 ± 0.13bC | 14.85 ± 0.49aB | 14.94 ± 0.50aB | 0.11 ± 0.01bB |
| TP               | 43.20 ± 0.89bC | 1.94 ± 0.10aC | 16.08 ± 1.35aAB | 16.20 ± 1.35aAB | 0.12 ± 0.01aAB |
| GR               | 42.67 ± 0.52bC | 2.16 ± 0.11bB | 15.97 ± 0.53aA | 16.12 ± 0.54aAB | 0.13 ± 0.01aA |
| TPGR             | 45.64 ± 1.23aABC | 1.92 ± 0.16aB | 16.17 ± 0.71aAB | 16.28 ± 0.73aBC | 0.12 ± 0.01aB |
| **120 DAYS**     |            |            |            |            |            |
| Control          | 38.64 ± 0.83cC | 1.40 ± 0.10bC | 12.75 ± 0.86bC | 12.82 ± 0.86bC | 0.11 ± 0.01aB |
| TP               | 41.95 ± 0.81bC | 1.69 ± 0.14abD | 15.53 ± 1.23bA | 15.62 ± 1.24aAB | 0.11 ± 0.01aB |
| GR               | 41.24 ± 0.67bD | 1.63 ± 0.11abcC | 15.78 ± 0.82aA | 15.86 ± 0.83aB | 0.10 ± 0.01aB |
| TPGR             | 44.28 ± 1.77aBC | 1.61 ± 0.19aC | 16.30 ± 0.55aAB | 16.38 ± 0.58aBC | 0.10 ± 0.01aC |
| **160 DAYS**     |            |            |            |            |            |
| Control          | 34.97 ± 1.70cD | 0.55 ± 0.18bD | 9.47 ± 0.84cD | 9.48 ± 0.86cD | 0.06 ± 0.02bC |
| TP               | 40.06 ± 0.51bD | 1.31 ± 0.18eE | 11.30 ± 1.36bC | 11.38 ± 1.37bC | 0.12 ± 0.03aAB |
| GR               | 40.43 ± 1.05bD | 1.27 ± 0.13D | 13.61 ± 1.31abB | 13.67 ± 1.31bcC | 0.09 ± 0.02abB |
| TPGR             | 43.93 ± 0.60aC | 1.52 ± 0.10aC | 14.82 ± 1.55bB | 14.89 ± 1.56aC | 0.10 ± 0.01aBC |

*TP: tea polyphenols; GR, 6-gingerol; TPGR, tea polyphenols + 6-gingerol; C*ab, chroma value; H°ab, hue value. Values are the mean of three replications ± standard deviation. Means between the treatments with different small letters are significantly different (p < 0.05). Means as storage time with different capital letters are significantly different (p < 0.05).*

### Effect of Tea Polyphenols in Combination with 6-gingerol Treatment on TVB-N

The TVB-N, which is mainly composed of ammonia and primary, secondary and tertiary amines, is widely used as an indicator of aquatic products spoilage. TVB-N values of shrimp paste during 25°C storage were gradually increased (Figure 1A). The increasing order of TVB-N values with different treatments at day 160 were: TPGR (85.13 mg N/100 g) < GR (95.75 mg N/100 g) < TP (113.02 mg N/100 g) < Control (178.05 mg N/100 g). Values of control samples were significantly (p < 0.05) higher than TP and GR treated samples. The shrimp paste samples contained TPGR had the higher effect of TVB-N inhibition (p < 0.05) than the TP or GR samples from day 40 to the end. The increase of TVB-N is related to the activity of spoilage bacteria (Kim et al., 2003; Cai et al., 2014). The associated addition of antibacterial tea polyphenols and 6-gingerol may have the intensified action on inhibiting the microbial decomposition of shrimp paste protein. Total visible counts (TVC) increased mentioned subsequently (Figure 2) during storage could explain the rise of TVB-N.

### Effect of Tea Polyphenols in Combination with 6-gingerol Treatment on TBA Value

TBA values represent the content of secondary lipid oxidation products, mainly malonaldehyde (MDA), which contribute to off-flavor in oxidized foods. Figure 1B shows changes in TBA values of treated and control shrimp paste during 160 days’ storage. The lipid oxidation was accelerated as storage progressed due to the enzyme released by microorganisms and aerobic storage. The initial TBA values of the control samples were 0.21 mg/kg sample and increased to 0.76 mg/kg sample after 160 days storage. TP and GR reduced the final TBA values by 23.7 and 28.9% than the control samples, respectively, and GR had the higher inhibitory effect, showing the stronger antioxidation than TP. TBA is an appropriate indicator to assess lipid oxidation due to its relatively simple measurement and correlation with the sensory quality of food. Shrimp paste treated with TPGR had the lowest TBA value (0.46 mg/kg sample) at the end of storage. This may due to strong antioxidant activity of spice extracts and synergistic effect with tea polyphenols. These results were consistent with studies done by Zhao et al. (2013) who reported that large yellow croaker immersed with tea.
polyphenols enhanced fish muscle quality and Cai et al. (2015b) who reported that red sea bream fillets treated with 6-gingerol inhibited the increase of TBA. Additionally, Bandyopadhyay et al. (2008) indicated the synergistic effectiveness of natural antioxidants in controlling lipid oxidation in dairy dessert.

**Effect of Tea Polyphenols in Combination with 6-gingerol Treatment on Total Amino Acids**

Table 2 presents the total amino acids content of shrimp paste after 160 days’ storage. Total amino acids content of 4819.60 mg/100 g of control samples decreased to 4478.24 mg at day 80 (data were not shown), but it decreased sharply from days 80 to 160. The major total amino acids present in the samples were aspartic acid, glutamic acid, glycine, valine, leucine and lysine, and most of them significantly decreased up to day 160 ($p < 0.05$). Lysine, as the highest content, which is a limited amino acid in grains such as rice, in the shrimp paste may act as a nutritional supplement. The TPGR samples had a significantly ($p < 0.05$) higher content of lysine than the TP or GR samples at the end of storage. The decline in the total amino acids content could be attributed to its degradation to amines, volatile acids, and other nitrogenous substances as by-products of bacterial metabolism or enzymatic decomposition (Izquierdo Canas et al., 2008). Additionally, the observed decline in amino acids would be also related with the formation of maillard reaction products (Faithong and Benjakul, 2014), as manifested by the deepening in color.
showing the higher inhibitory capacity (Cai et al. 2015b) were reduced compared to control in salted and fermented shrimp paste (Kumudavally et al. 2008) inhibit the formation of histamine in shrimp paste, 6-gingerol did significantly decreased the level of histamine in TP or GR samples suggested that tea polyphenols combined with 6-gingerol treatment inhibited the formation of histamine, putrescine and cadaverine. The type and amount of biogenic amines formed during storage depends on many factors, such as shrimp species, microbial flora, packaging, temperature and use of antimicrobial agents (Moon et al., 2010). Table 3 shows the effects of different treatments on biogenic amines in the samples throughout the storage time. The initial shrimp paste had low biogenic amines level (<50 mg/kg), which was within the safe level for human health. Histamine is the causative agent for shrimp products poisoning, the toxic effects of which are intensified by the presence of other amines, such as putrescine and cadaverine. The highest histamine concentration was observed in the control samples (113.37 mg/kg), and lower level of histamine in TP or GR samples suggested that tea polyphenols inhibited the growth of bacteria with histidine decarboxylase activity. Kumudavally et al. (2008) reported the effects of tea polyphenols on biogenic amines formation in mutton stored at ambient temperature. They found that tea polyphenols had potential inhibition effects on cadaverine and other BAs accumulation in mutton muscle. Cai et al. (2015a) studied that red drum filets treated with spice essential oils inhibited the formation of histamine, putrescine and cadaverine. Similarly, the contents of putrescine, histamine and tyramine were reduced compared to control in salted and fermented anchovy treated with garlic and other spices extracts, respectively, showing the higher inhibitory capacity (Mah et al., 2009). In brief, tea polyphenols combined with 6-gingerol did significantly (p < 0.05) inhibit the formation of histamine in shrimp paste during storage. These could be attributed that both tea polyphenols and 6-gingerol have antimicrobial and antioxidant properties. Tyramine was not detected at the beginning of storage.

### Table 2: Changes in total amino acids of shrimp paste treated with tea polyphenols + 6-gingerol stored at 25°C for 160 days.

| Amino acids | Control | TP | GR | TPGR |
|-------------|---------|----|----|------|
|             | 0 day   | 160 days | 0 day | 160 days | 0 day | 160 days | 0 day | 160 days |
| Asp         | 477.72 ± 13.99a | 379.56 ± 4.59c | 483.14 ± 6.76a | 447.65 ± 5.07b | 482.91 ± 10.47a | 468.34 ± 5.73a | 479.30 ± 4.72a | 466.31 ± 4.76a |
| Thr         | 214.94 ± 2.00a | 174.96 ± 4.10c | 213.94 ± 3.11a | 191.89 ± 2.23b | 213.74 ± 5.18a | 193.84 ± 1.45b | 213.99 ± 4.40a | 204.00 ± 4.63a |
| Ser         | 159.96 ± 5.36a | 135.59 ± 2.60b | 160.38 ± 3.58a | 146.92 ± 3.30a | 161.67 ± 4.97a | 147.64 ± 1.96a | 163.49 ± 4.52a | 151.05 ± 3.19a |
| Glu         | 381.98 ± 7.70a | 300.59 ± 11.88b | 380.85 ± 4.51a | 354.68 ± 12.15a | 384.29 ± 7.51a | 359.62 ± 3.91a | 384.31 ± 2.57a | 365.96 ± 5.59a |
| Gly         | 427.45 ± 8.47a | 384.19 ± 7.05c | 421.83 ± 4.03a | 389.25 ± 7.39b | 420.55 ± 7.39a | 389.92 ± 4.06b | 422.48 ± 5.80a | 408.72 ± 5.85a |
| Ala         | 249.49 ± 7.90a | 166.67 ± 6.05c | 244.11 ± 5.50a | 209.81 ± 6.78b | 248.16 ± 5.26a | 219.70 ± 4.12b | 246.18 ± 4.33a | 234.60 ± 6.29a |
| Cys         | 35.51 ± 2.87a | 22.29 ± 1.39c | 37.72 ± 5.78a | 29.87 ± 1.67b | 35.83 ± 1.64a | 31.69 ± 8.18b | 36.54 ± 3.01a | 33.40 ± 1.42a |
| Val         | 421.81 ± 3.05a | 295.26 ± 9.39c | 418.80 ± 7.30a | 383.07 ± 6.96b | 419.80 ± 4.74a | 385.32 ± 9.27b | 416.80 ± 1.75a | 401.95 ± 5.03a |
| Met         | 94.68 ± 3.49a | 61.92 ± 3.06b | 93.80 ± 2.19a | 82.53 ± 4.10a | 93.02 ± 4.89a | 78.98 ± 4.12a | 94.09 ± 1.49a | 85.34 ± 2.51a |
| Ile         | 236.44 ± 5.71a | 178.67 ± 4.71c | 237.58 ± 2.64a | 209.28 ± 7.46b | 237.95 ± 5.54a | 208.84 ± 4.58b | 237.21 ± 2.21a | 223.58 ± 4.71a |
| Leu         | 375.52 ± 4.80a | 308.59 ± 3.66c | 376.72 ± 5.33a | 339.62 ± 5.35b | 375.54 ± 0.82a | 347.09 ± 4.34b | 379.17 ± 4.84a | 365.33 ± 8.40a |
| Tyr         | 113.89 ± 8.21a | 74.90 ± 2.27b | 110.53 ± 4.56a | 97.31 ± 3.93a | 111.82 ± 7.62a | 96.43 ± 4.68a | 113.74 ± 7.80a | 101.62 ± 3.80a |
| Phe         | 338.42 ± 5.04a | 253.95 ± 3.86c | 334.46 ± 3.26a | 286.57 ± 2.56c | 337.98 ± 9.06a | 295.39 ± 3.40b | 337.51 ± 2.84a | 304.87 ± 3.44a |
| Lys         | 610.46 ± 5.35a | 514.01 ± 5.32c | 613.77 ± 5.49a | 574.66 ± 8.06b | 612.25 ± 6.42a | 575.77 ± 6.06b | 615.54 ± 3.54a | 586.91 ± 5.54a |
| His         | 80.11 ± 4.79a | 58.59 ± 5.31b | 79.73 ± 4.12a | 77.15 ± 1.62a | 86.26 ± 3.59a | 74.47 ± 5.00a | 81.79 ± 3.45a | 76.87 ± 4.23a |
| Arg         | 312.37 ± 3.50a | 236.58 ± 5.80d | 312.20 ± 6.63a | 277.89 ± 4.26c | 312.51 ± 6.15a | 290.40 ± 4.15b | 314.52 ± 2.55a | 302.24 ± 6.59a |
| Pro         | 288.86 ± 4.41a | 208.77 ± 6.57b | 286.74 ± 6.27a | 256.03 ± 2.65a | 283.34 ± 1.66a | 259.74 ± 5.23a | 286.57 ± 2.50a | 264.64 ± 3.44a |

Total 4819.60 3690.74 4806.31 4364.17 4817.62 4423.19 4823.22 4577.39

TP: tea polyphenols; GR, 6-gingerol; TPGR, tea polyphenols + 6-gingerol; Ctab, chroma value; H2ab, hue value. Values are the mean of three replications ± standard deviation. Means between the treatments with different small letters are significantly different (p < 0.05).
period, and TPGR had the greatest inhibitory effects on tyramine, tryptamine and phenylethylamine in shrimp paste. Spermidine and spermine were not detected in samples throughout the storage period.

Effect of Tea Polyphenols in Combination with 6-gingerol Treatment on Sensory Evaluation

Results in Figure 2B revealed the sensory changes of shrimp paste with different treatments during 25°C storage. Color, aroma, flavor and juiciness of control samples were given “unacceptable” scores by the end of storage period. The results of sensory evaluation were correlated with TVC and chemical analyses. The antioxidant and antimicrobial effects of TPGR had been shown to prolong the shelf life of shrimp paste by 40–60 days as compared to the control samples.

Conclusion

The effect of tea polyphenols combined with 6-gingerol (TPGR) on the biogenic amines inhibition and quality of shrimp paste

| TABLE 3 | Changes in biogenic amines of shrimp paste treated with tea polyphenols + 6-gingerol stored at 25°C for 160 days. |
| BAs | Treatments | Days |
| PUT | Control | 0 | 40 | 80 | 120 | 160 |
| TP | 5.13 ± 0.38aE | 15.39 ± 2.81aD | 31.07 ± 2.51aC | 55.14 ± 2.42aB | 78.20 ± 2.88aA |
| CAD | Control | 7.17 ± 0.82aE | 12.98 ± 1.97aD | 18.84 ± 0.88aC | 28.96 ± 0.39aB | 43.28 ± 1.80aA |
| CAD | TP | 7.50 ± 0.35aE | 12.98 ± 1.97aD | 18.84 ± 0.88aC | 28.96 ± 0.39aB | 43.28 ± 1.80aA |
| CAD | TPGR | 7.47 ± 0.04aE | 12.98 ± 1.97aD | 18.84 ± 0.88aC | 28.96 ± 0.39aB | 43.28 ± 1.80aA |
| HIM | Control | 17.09 ± 1.15aE | 27.85 ± 1.72aD | 49.35 ± 2.02aC | 74.32 ± 2.84aB | 113.37 ± 5.24aA |
| HIM | TP | 17.42 ± 2.06aE | 27.85 ± 1.72aD | 49.35 ± 2.02aC | 74.32 ± 2.84aB | 113.37 ± 5.24aA |
| HIM | TPGR | 17.95 ± 0.88aE | 27.85 ± 1.72aD | 49.35 ± 2.02aC | 74.32 ± 2.84aB | 113.37 ± 5.24aA |
| PHE | Control | 2.56 ± 0.27aE | 7.93 ± 0.22aD | 16.04 ± 1.60aC | 24.93 ± 0.34aB | 35.88 ± 1.27aA |
| PHE | TP | 2.53 ± 0.27aE | 7.93 ± 0.22aD | 16.04 ± 1.60aC | 24.93 ± 0.34aB | 35.88 ± 1.27aA |
| PHE | TPGR | 2.68 ± 0.30aE | 7.93 ± 0.22aD | 16.04 ± 1.60aC | 24.93 ± 0.34aB | 35.88 ± 1.27aA |
| TRY | Control | 8.02 ± 0.43aE | 21.21 ± 1.66aD | 37.76 ± 1.88aC | 57.01 ± 2.59aB | 85.26 ± 1.95aA |
| TRY | TP | 7.89 ± 0.48aE | 21.21 ± 1.66aD | 37.76 ± 1.88aC | 57.01 ± 2.59aB | 85.26 ± 1.95aA |
| TRY | TPGR | 8.00 ± 0.75aE | 21.21 ± 1.66aD | 37.76 ± 1.88aC | 57.01 ± 2.59aB | 85.26 ± 1.95aA |
| TYR | Control | ND | 17.10 ± 2.08aD | 44.06 ± 2.31aC | 67.76 ± 2.36aB | 95.80 ± 4.15aA |
| TYR | TP | ND | 17.10 ± 2.08aD | 44.06 ± 2.31aC | 67.76 ± 2.36aB | 95.80 ± 4.15aA |
| TYR | TPGR | ND | 17.10 ± 2.08aD | 44.06 ± 2.31aC | 67.76 ± 2.36aB | 95.80 ± 4.15aA |
| SPD | Control | ND | ND | ND | ND | ND |
| SPD | TP | ND | ND | ND | ND | ND |
| SPD | TPGR | ND | ND | ND | ND | ND |
| SPM | Control | ND | ND | ND | ND | ND |
| SPM | TP | ND | ND | ND | ND | ND |
| SPM | TPGR | ND | ND | ND | ND | ND |

PUT, putrescine; CAD, cadaverine; HIM, histamine; PHE, 2-phenylethylamine; TRY, tryptamine; TYR, tyramine; SPM, spermine; SPD, spermidine; ND, not detected. Values are the mean of three replications ± standard deviation. Different small letters in the same column indicate significant differences between means (p < 0.05). Different capital letters in the same row indicate significant differences between means (p < 0.05).
stored at 25°C for 160 days was investigated. Shrimp paste color, total volatile basic nitrogen, thiobarbituric acid reactive substances, total amino acids, biogenic amines, microbial, and sensory quality were measured. Our research exhibited that the quality preservation of ambient-stored shrimp paste by TPGR treatment involved the maintenance of color, total amino acids content and sensory quality, reduction of microbial counts, inhibition of biogenic amines compared with control. TPGR samples also showed lower levels of TVB-N and TBA value during storage. These results indicate that TPGR is promising as a synergistic preservative to be used for maintaining fish and fish products quality and extending their shelf-life.

Acknowledgments

This study was supported by National Natural Science Foundation of China (31401478; 31471639), National Postdoctoral Science Foundation of China (2015M570760), China Scholarship Council (201508210023) and Aquatic Products Processing and Safety Key Laboratory of Guangdong Province (GDPKLAPPS1402).

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**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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