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Evaluation of different tea extracts on dough, textural, and functional properties of dry Chinese white salted noodle

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ABSTRACT

Green tea extract (GTE), black tea extract (BTE) and oolong tea extract (OTE) were added into noodle formulation at 0.5–2.0% levels (based on flour weight) to produce dry Chinese white salted noodles with enhanced antioxidant capacity and starch digestion inhibitory ability. Dough mixing properties, and subsequent noodle color, cooking yield and cooked noodle texture were affected by the tea extract level and type. Meanwhile, the total phenolic contents (0.23–0.90 GAE g/100 g dry weight), DPPH free radical scavenging activity (1.96–6.25 g DPPH/100 g dry weight) and resistant starch content (0.64–18.48 g/100 g, dry weight) of noodles increased as the tea extract addition increased from 0.0 to 2.0%. The predicted glycemic index (pGI) had the greatest reduction from 91.12% for control to 76.23% for 2.0% OTE. Tea extracts at 1.0–2.0% addition levels are recommended as they had little effect on the cooking qualities of noodles, but were very effective to improve the antioxidant properties and glycemic response control.

1. Introduction

Nowadays, the world is facing a dramatic increase in chronic diseases, such as overweight, cardiovascular disease, diabetes, and constipation, which is mainly attributed to the ingestion of more saturated fat, refined sugar, and overly processed foods, and less dietary fiber (BM, 2006). Although the management of chronic disease has been more effective in most high-income countries of the world through diet revolution for many decades, the outlook for the condition is not optimistic in low- and middle-income countries (Paradis & Chiolero, 2011). White salted noodles (WSN), as one of the primary noodle products consumed mainly in China, Japan, and Korea are made from a basic formula containing wheat flour, water, and salt (Hou, 2010). The popularity and simplicity of noodles make them an optimal foundation for incorporation of functional ingredients to improve diet.

Tea is a popular drink that originated from Asia and generally classified into green tea, black tea, and oolong tea based on the processing technology. Tea shoots are steamed or roasted to avoid enzymatic oxidation to make green tea. Catechins and its derivatives are a major group of phenolic compounds in green tea (Kim, Goodner, Park, Choi, & Talcott, 2011). Nevertheless, for black tea manufacturing, a fermentation process occurs before drying when the enzymes are released from cells by crushing of the tea shoot (generally more than 80% fermented). Oolong tea has a similar processing method, but the degree of fermentation is significantly shortened (fermented from 20% to 60%). The tea catechins undergo oxidative polymerization by polyphenol oxidase, which leads to the formation of larger polyphenolic molecules (dimer or polymer) such as theaflavins and thearubigins in the fermentation process (Balentine, Wiseman, & Bouwens, 1997).

As the most biologically active group of the tea components, tea polyphenols (TPs) have great potential in preventing or reducing the risk of oxidation-linked chronic diseases, such as diabetes, cardiovascular diseases, and cancers (Higdon & Frei, 2003). Moreover, the inhibitory effect against starch digestion and the ability to reduce the postprandial hyperglycemia of TPs has also been reported. Traditional wheat-based products, such as biscuit (Sharma & Zhou, 2011), sponge cake (Lu, Lee, Mau, & Lin, 2010), whole wheat flour pan bread (Ning, Hou, Wan, & Dubat, 2017), Chinese steamed bread (Zhu, Sakulnak, & Wang, 2016), and white bread (Goh et al., 2015) were innovated through incorporation of TPs to improve antioxidant capacity or inhibit

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starch digestibility. However, due to the different processing conditions (heat, fermentation), different sources (green tea, black tea, and oolong tea), and carriers (tea powder, tea extract, and pure TPs) of TPs, the functional abilities exhibit in varying effects on different products. At the same time, the dough rheology and end-product quality are also affected. Therefore, apart from the nutritional benefits of polyphenols, their influences on the process properties and noodle qualities, such as color and texture, should also be taken into account.

Until now, only Li et al. (2012) used superfine green tea powder to substitute wheat flour to make fresh noodles. The results showed the improvement of dough stability, the inhibition of starch retrogradation, and the increase of noodle hardness/chewiness. We have not found any published reports on interactions between different TPs and wheat-based noodles. Considering the negative effect of fiber from tea powder on noodle texture and appearance, tea extract, which is a cheap source of TPs and can be solubilized in water or blended in a dry ingredients formulation easily, may be a better choice.

The objective of the study was to investigate the effect of different TPs supplements (green tea extract, black tea extract, and oolong tea extract) on the quality characteristics of dry Chinese WSN. Meanwhile, the antioxidant capacity and in-vitro starch digestibility of WSNs incorporated with different tea extracts were also explored.

2. Materials and methods

2.1. Materials

Hard red winter (HRW) flour was milled in a pilot-scale Miag flour mill (Buhler-Miag Co., Switzerland) at Wheat Marketing Center (Portland, OR, USA). The moisture, protein, and ash content of the flour were 14.45 g/100 g, 10.27 g/100 g (14% moisture basis), and 0.454 g/100 g (14% moisture basis), respectively. Green tea extract (GTE), Black tea extract (BTE), and Oolong tea extract (OTE) were purchased from Damin Foodstuff Co., Ltd (Zhangzhou, Fujian, China). Tea extracts were stored at 5 °C with no light exposure until use. The moisture content for GTE, BTE, and OTE were 6.07 g/100 g, 6.59 g/100 g, and 4.37 g/100 g, respectively. All other enzymes and chemicals were purchased from Sigma–Aldrich (St Louis, MO, USA).

2.2. Dough mixing properties by Mixolab

The Mixolab (Chopin Technologies, Villeneuve la Garenne, France) was used to determine the dough mixing properties of flour samples according to the method 54–60.01 (AACCI, 2010). Water absorption (WA, %), dough development time (DT, min), dough stability time (ST, min), starch gelatinization speed (β), and different torque (C1, C2, C3, C4, C5) during different periods (Nm) were obtained from the recorded curve. Dough strength weakening (C1-C2, Nm) and starch retrogradation (C5-C4, Nm) were calculated.

2.3. Noodle making

WSN were processed using the method described by Hou (2010) on a pilot-scale noodle line. The basic formulation was composed of 100% flour, 1.2% salt, and 28% water. Different tea extracts (0.5%, 1.0%, and 2.0% of flour weight) were pre-mixed in a salt solution and added to the flour during dough mixing. The resultant noodle strands (300 mm L × 2.5 mm W × 1.2 mm T) were dried in a drying chamber (Model SCC WE 62G, Rational, USA) in four stages: stage 1 (75% humidity and 30 °C for 0.5 h), stage 2 (50% humidity and 40 °C for 3.0 h), stage 3 (25% humidity and 60 °C for 4.5 h), and stage 4 (25% humidity and 30 °C for 1.0 h). The noodles are packed and stored in cool condition until evaluation.

2.4. Noodle color measurement

Color values of the fresh and dry WSN were determined by a Chroma Meter (Konica Minolta CR-400, Japan) using the L* a* b* color system (Hou, 2010). After production, three small dough pieces (8 cm × 8 cm) were cut from the final dough sheet and layered together on a whiteboard. Each dough piece was measured twice at different point on each side at 0 h and 24 h. Color measurements of each sample were the average of 8 individual determination. Dried noodles were ground (Perten Instruments, Sweden) and sieved through 28-mesh; the color of the obtained noodle powder was measured using a granular materials attachment.

2.5. Dry white salted noodles cooking yield

The measurement of dry WSN cooking yield followed the method of Hou (2010). The cooking yield was expressed in Eq (1). The obtained noodles were kept in a covered bowl for texture test.

$$\text{Cooking yield} = \frac{\text{the weight after cooking} - \text{the weight before cooking}}{\text{the weight before cooking}} \quad (1)$$

2.6. Cooked noodles texture

The analysis of cooked dry WSN texture followed the method of Hou (2010) using a TA-XTPlus Texture Analyzer (Texture Technology Corp., Scarsdale, New York). The values of hardness (N), springiness, adhesiveness (N.s), chewiness (N), and resilience of the cooked noodles were recorded. The cross-section area was about 62.5 mm^2. The test was done within 6 min to minimize textural changes. Within-batch coefficient of variance (CV, %) of the hardness values should be smaller than 5%.

2.7. Sample preparation for TPC, antioxidant capacity and starch digestibility tests

Sample extraction followed the method of Segundo, Roman, Gomez, and Martinez (2017). In brief, each noodle powder (1.0 g) was extracted with methanol-water (methanol/water, 50:50, v/v, 50 mL) acidified by HCl (pH = 2) for 16 h, followed with acetone (acetone/water, 70/30, v/v, 50 mL) for 60 min at 25 °C under constant stirring. The phenolic content and antioxidant ability were measured using the combined supernatants from the two extractions.

2.8. Total phenolic content (TPC)

TPC was measured following the Folin-Ciocalteu procedure. Sample extract (0.1 mL) and Folin-Ciocalteu reagent (1.0 mL) were mixed together. The mixture was continually stirred for 10 min, followed by the addition of 7 g/100 mL sodium carbonate solution (1.0 mL) and distilled water (3.0 mL). The absorbance was performed at 765 nm. TPC was expressed as mg of gallic acid equivalents/100 g dry matter.

2.9. Antioxidant capacity

The antioxidant activity of noodle samples was evaluated based on the principle of the DPPH free radical scavenging. Four aliquots (50, 100, 250, and 500 μL) of each sample extract were mixed with methanolic DPPH solution (1.0 mL). The absorbance at 517 nm was recorded during 5 min and fit by linear regression. The concentration at which DPPH radicals were scavenged by 50% was expressed as IC_{50} (g/100 g dry matter).

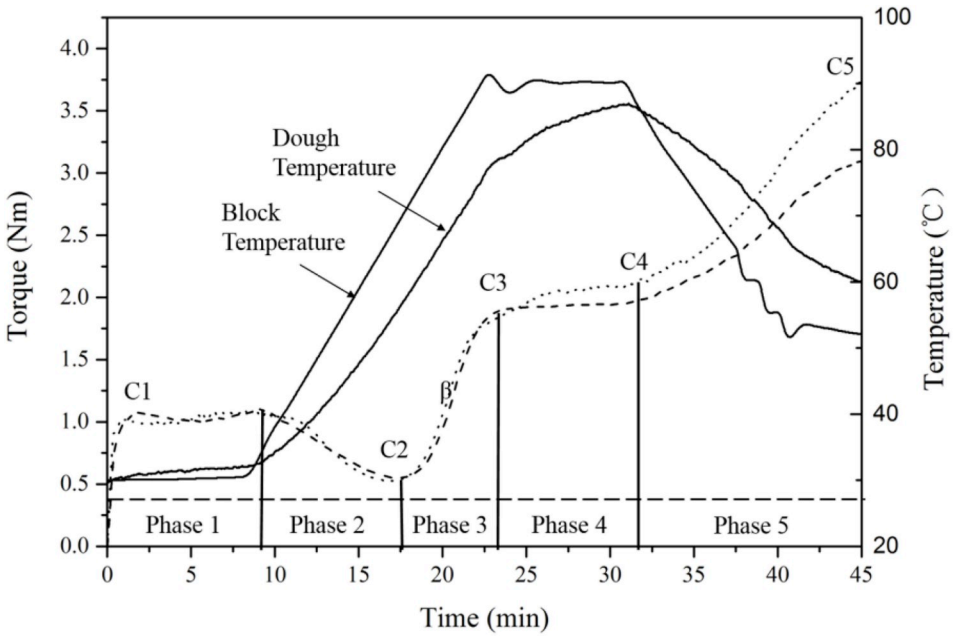

Fig. 1. Mixolab curves of hard red winter flour doughs added with 0.0% and 2.0% tea extracts. Dash line (- - -) represents torque change of control hard red winter flour dough; Dot line (·····) represents torque change of hard red winter flour dough added with 2.0% black tea extract.
Phase 1: dough development; Phase 2: dough weakening; Phase 3: starch swelling and gelatinization; Phase 4: hot gel stability; Phase 5: starch retrogradation. The detailed description of each phase is stated in the Results and Discussion.
C1: the maximum torque in Phase 1; C2: the minimum torque in Phase 2; C3: the peak torque in Phase 3; C4: the latest torque in Phase 4; C5: the maximum torque in Phase 5; β: slope of ascending torques in Phase 3.

2.10. In-vitro carbohydrate digestibility and predictive glycemic index

The *in-vitro* starch digestibility protocol was based on the method of Englyst, Kingman, and Cummings (1992). Briefly, porcine pancreatin (6.0 g) was homogenized in deionized water (40 mL) with constant mixing at 25 °C for 10 min followed by centrifugation. The mixture solution of pancreatin supernatant (32 mL), amyloglucosidase (2.0 mL) and deionized water (3.0 mL) was freshly prepared as simulated small intestine digestive juice. Noodle powder (500 mg) were gelatinized or retrograded with distilled water (10 mL), followed by the addition of 5 g/L guar gum prepared in 0.05 mol/L HCl (10 mL) and 0.5 mol/L sodium acetate solution (5.0 mL). The simulated small intestine digestive juice (10 mL) was added to the sample solution to mimic the digestion occurred in human small intestine. The starch hydrolysis was operated in a shaking bath (37 °C) with continuous stirring at 170 rpm. Aliquots (0.5 mL) were withdrawn at 20, 60, and 120 min and diluted immediately with 80% ethanol (4.0 mL). The glucose content was evaluated with glucose oxidase and peroxidase assay kits. The total starch content (TS) in the starch samples was calculated as the glucose released by completely enzymatic hydrolysis. Rapidly digestible starch (RDS) content and slowly digestible starch (SDS) content were calculated by using the amount of starch digested at 20 min and a further 100 min, respectively. Resistant starch (RS) was calculated following Eq (2):

$$RS = TS - (RDS + SDS) \quad (2)$$

The predictive glycemic index (pGI) was determined according to the equation established by Goni, Garcia-Alonso, and Saura-Calixto (1997): $C = C_\infty[1\text{-}\exp(-kt)]$, where C, C_∞, k stand for the starch hydrolysis degree at time t, the glucose concentration released at 120 min and the kinetic constant, respectively. The hydrolysis index (HI) was measured as the ratio between the area under the samples hydrolysis curve (AUC) and a reference sample (white bread). The pGI was calculated from Eq (3).

$$pGI = 8.198 + 0.862 \times HI \quad (3)$$

2.11. Statistical analysis

All analysis were carried out in duplicate for Mixolab, color, cooking yield, and texture tests, and in triplicate for total phenolic content, antioxidant capacity, and digestion tests. SPSS (version 16.0) for Windows (SPSS Inc, Chicago, USA) was used to perform data analysis. The differences between treatments were evaluated by one-way analysis of variance (ANOVA) with Duncan's test at the level of 0.05.

3. Results and discussions

3.1. Dough mixing properties

In Mixolab, the torque produced by passage of dough between two kneading arms was recorded (as shown in Fig. 1) to study the gluten quality and starch pasting behavior in the same test. Detailed description of the physical change and corresponding parameters of Mixolab measurement was reported by Rosell, Collar, and Haros (2007). The parameters WA, DT, ST, C2 and C2-C1 are used to evaluate the gluten quality. C3, C4, C5-C4, and slope β parameters represent starch pasting properties of the dough system during heating and cooling cycle (Ding et al., 2018).

In Table 1, the WA for HRW was 59.6% and decreased significantly ($p < 0.05$) at the higher level of each tea extract and especially for GTE, which was attributed to the competition effect between highly hydrophilic properties in tea extract and wheat protein. The DT of control was 9.1 min; however, it was decreased to 8.0 min with the addition of 2.0% tea extracts except for BTE, which showed a faster dough formation. The ST of control was 10.4 min, whereas it was significantly ($p < 0.5$) increased to 12.5 min by 2.0% GTE addition, 13.0 min by 2.0% BTE addition, and 11.6 min by 2.0% OTE addition. This indicates that the dough was more tolerant to mixing with the addition of tea extracts, especially for BTE at 2.0% level. The parameter C1-C2 decreased when the GTE and BTE additions were at 2.0%, while OTE seemed to have an opposite effect.

TPs appeared to have a mixed effect on gluten formation. On the one hand, as an antioxidant, TPs have reducing power, which gives rise to the reduction of the disulfide bond and the increase of thiol (SH) group in a dough system (Wang, Zhou, Yu, & Chow, 2006). On the other hand, both covalent and non-covalent interactions exist in a protein-polyphenol system. Covalent binding often happens between functional groups of protein and quinones formed by polyphenol oxidation (Bordenave, Hamaker, & Ferruzzi, 2014). The hydrophobic and hydrogen bonding are two main non-covalent combined forces between phenolic compounds and proteins (Prigent et al., 2003). It seems the tea

Table 1
Mixolab properties of hard red winter flour added with different tea extracts.

Sample	WA (%)	DT (min)	ST (min)	C1-C2 (Nm)	C3 (Nm)	C4 (Nm)	C5-C4 (Nm)	β
Control	59.6%	9.05 ± 0.11^{cd}	10.39 ± 0.06^{b}	0.56 ± 0.00^{c}	1.86 ± 0.00^{de}	1.94 ± 0.00^{a}	1.14 ± 0.02^{a}	0.36 ± 0.00^{b}
0.5% GTE	59.0%	9.88 ± 0.04^{cd}	10.87 ± 0.05^{bc}	0.53 ± 0.00^{b}	1.86 ± 0.01^{de}	2.05 ± 0.00^{d}	1.45 ± 0.00^{cd}	0.45 ± 0.01^{c}
1.0% GTE	57.8%	8.05 ± 0.81^{a}	11.67 ± 0.26^{d}	0.53 ± 0.02^{b}	1.90 ± 0.04^{ef}	2.09 ± 0.01^{d}	1.47 ± 0.04^{d}	0.45 ± 0.04^{c}
2.0% GTE	57.0%	8.05 ± 0.04^{a}	12.49 ± 0.23^{e}	0.51 ± 0.00^{b}	1.94 ± 0.03^{f}	2.06 ± 0.02^{d}	1.20 ± 0.07^{ab}	0.42 ± 0.02^{bc}
0.5% BTE	59.2%	9.35 ± 0.03^{cd}	10.26 ± 0.25^{b}	0.57 ± 0.01^{cd}	1.78 ± 0.01^{bc}	1.96 ± 0.01^{ab}	1.14 ± 0.00^{a}	0.34 ± 0.01^{b}
1.0% BTE	58.4%	8.64 ± 0.27^{abc}	11.10 ± 0.45^{cd}	0.52 ± 0.01^{b}	1.82 ± 0.00^{cd}	2.00 ± 0.00^{c}	1.25 ± 0.06^{b}	0.38 ± 0.06^{bc}
2.0% BTE	57.4%	9.42 ± 0.21^{cd}	13.05 ± 0.17^{e}	0.43 ± 0.00^{a}	2.04 ± 0.00^{g}	1.99 ± 0.00^{bc}	1.24 ± 0.01^{b}	0.15 ± 0.07^{a}
0.5% OTE	59.7%	8.09 ± 0.27^{ab}	8.85 ± 0.54^{a}	0.62 ± 0.01^{e}	1.77 ± 0.02^{ab}	1.94 ± 0.02^{a}	1.18 ± 0.01^{ab}	0.35 ± 0.02^{b}
1.0% OTE	59.5%	8.95 ± 0.42^{bc}	10.16 ± 0.39^{b}	0.59 ± 0.01^{d}	1.74 ± 0.02^{ab}	1.94 ± 0.01^{a}	1.22 ± 0.01^{ab}	0.37 ± 0.01^{bc}
2.0% OTE	58.2%	8.03 ± 0.57^{a}	11.60 ± 0.17^{d}	0.56 ± 0.00^{c}	1.72 ± 0.02^{a}	1.96 ± 0.02^{a}	1.37 ± 0.07^{c}	0.39 ± 0.03^{bc}

WA: Water Absorption; DT: Dough development time; ST: Stability time; C1-C2: The protein network strength under increasing heating; C3: The rate of starch gelatinization; C4: The stability of the hot gel; C5-C4: The anti-aging effect of the starch; β: Starch gelatinization speed.
Control: Hard red winter flour (HRW) without tea extract; 0.5%, 1.0%, and 2.0% GTE: HRW with additional 0.5%, 1.0%, and 2.0% green tea extract, respectively; 0.5%, 1.0%, and 2.0% BTE: HRW with additional 0.5%, 1.0%, and 2.0% black tea extract, respectively; 0.5%, 1.0%, and 2.0% OTE: HRW with additional 0.5%, 1.0%, and 2.0% oolong tea extract, respectively; All addition levels were on a flour basis.
Results are presented as means ± standard deviations (n = 2). Means with different small letter superscripts in the same column are significantly different at $P < 0.05$.

extracts contributed more to protein-polyphenol binding effect in Mixolab testing.

C3 and C4 were both increased with the addition of each tea extract except for 2.0% BTE. 2.0% BTE promoted the starch gelatinization at the maximum level, which resulted in the peak torque occurring in the 3rd stage and the breakdown occurring subsequently in the 4th stage. The starch gelatinization speed (β) for control was 0.36 and was significantly decreased by 2.0% BTE, which showed the lowest value up to 0.15. In the last stage, all samples with tea extracts exhibited a higher retrogradation degree than the control, which was due to the higher degree of gelatinization (the higher C3 and C4 of samples added with tea extracts) in the pasting period.

3.2. Noodle color

As shown in Tables 2 and 3, an increase level of tea extracts from 0% to 2% substantially influenced the color of the fresh and dry WSN. In fresh noodles, the addition of tea extracts significantly ($p < 0.05$) decreased the L* and increased a* values. The b* values were only significantly ($p < 0.05$) increased at 1.0% and 2.0% GTE addition. The GTE was a yellow-green color which had a totally different L*, a* and b* from the flour. The orange-red color of BTE and OTE had a different L* and a* but had similar b* values to the flour. The color discrepancy of the tea extracts and control flour altered the color of their fresh noodles. Noodle darkening mostly occurred during 0–24 h after making (Asenstorfer, Appelbee, & Mares, 2009). The control noodle showed a lower L^*_{24h}, higher a^*_{24h} and b^*_{24h} over 24 h storage. Compared to the control, the incorporation of different tea extracts resulted in a decrease of L^*_{24h} and increase of a^*_{24h}. The change of b^*_{24h} showed a declining trend for BTE and OTE addition but an increasing trend for GTE addition. $\Delta L^*(L^*\text{-}L^*_{24h})$ is often used to evaluate noodle color stability during the 24 h period. All tea extracts accelerated the discoloration except for the 2% GTE. The highly polymerized melanic pigments, which were produced by the polymerization of TPs in the presence of PPO (Sava, Yang, Hong, Yang, & Huang, 2001), may be in relation to the discoloration of tea extract-incorporated noodles. Meanwhile, as the main precursor of melanin, the benzoquinones can be reduced back to dihydroxyphenols by TPs (Radha & Arthur, 1992). It can be speculated that there may be a balance of different effects in 2.0% GTE-substituted noodles, which resulted in a similar discoloration to the control.

Table 2
Color of fresh Chinese white salted noodles with different tea extracts.

Sample	Fresh Noodle sheet						
	L^*	a^*	b^*	L^*_{24h}	a^*_{24h}	b^*_{24h}	ΔL^*
Flour	92.32 ± 0.02^{a}	−1.98 ± 0.01^{c}	8.29 ± 0.05^{c}	/	/	/	/
GTE	65.35 ± 0.25^{d}	5.31 ± 0.29^{a}	29.90 ± 0.53^{a}	/	/	/	/
BTE	43.39 ± 0.57^{a}	9.93 ± 0.06^{b}	9.77 ± 0.54^{d}	/	/	/	/
OTE	46.40 ± 0.30^{a}	9.49 ± 0.13^{c}	13.02 ± 0.20^{b}	/	/	/	/
Control	83.78 ± 0.47^{h}	−0.3 ± 0.04^{a}	19.13 ± 1.19^{ab}	74.50 ± 0.12^{i}	0.06 ± 0.03^{a}	24.32 ± 0.20^{h}	9.3 ± 0.56^{a}
0.5% GTE	80.52 ± 0.27^{g}	0.68 ± 0.06^{b}	19.80 ± 0.55^{ab}	66.32 ± 0.11^{h}	3.23 ± 0.08^{b}	23.49 ± 0.15^{g}	14.20 ± 0.28^{c}
1.0% GTE	78.14 ± 0.63^{f}	0.88 ± 0.15^{c}	23.22 ± 0.93^{c}	64.62 ± 0.46^{g}	5.09 ± 0.22^{c}	28.98 ± 0.22^{i}	13.53 ± 0.40^{b}
2.0% GTE	71.84 ± 0.45^{e}	2.47 ± 0.21^{d}	30.16 ± 0.59^{d}	62.52 ± 0.37^{f}	5.63 ± 0.19^{d}	28.98 ± 0.18^{j}	9.33 ± 0.65^{a}
0.5% BTE	71.01 ± 0.62^{d}	5.34 ± 0.21^{g}	19.02 ± 0.98^{ab}	55.94 ± 0.56^{e}	7.34 ± 0.20^{g}	20.65 ± 0.33^{d}	15.07 ± 0.89^{d}
1.0% BTE	66.2 ± 0.71^{c}	6.66 ± 0.29^{i}	19.94 ± 1.09^{b}	49.37 ± 0.33^{c}	9.51 ± 0.17^{i}	20.33 ± 0.25^{c}	16.83 ± 0.92^{f}
2.0% BTE	60.84 ± 0.78^{b}	7.79 ± 0.33^{j}	19.60 ± 0.78^{ab}	44.55 ± 0.49^{b}	10.15 ± 0.20^{j}	17.98 ± 0.11^{a}	16.29 ± 0.65^{ef}
0.5% OTE	71.59 ± 0.49^{e}	3.82 ± 0.16^{e}	18.96 ± 0.58^{a}	56.36 ± 0.83^{e}	6.56 ± 0.26^{e}	21.54 ± 0.25^{f}	15.23 ± 0.72^{d}
1.0% OTE	66.07 ± 0.65^{c}	4.96 ± 0.22^{f}	19.30 ± 0.60^{ab}	50.03 ± 0.68^{d}	8.36 ± 0.26^{h}	20.92 ± 0.11^{e}	16.03 ± 0.71^{e}
2.0%OTE	58.69 ± 0.42^{a}	6.27 ± 0.19^{h}	19.84 ± 0.44^{ab}	44.04 ± 0.15^{a}	9.41 ± 0.10^{i}	18.69 ± 0.23^{b}	14.65 ± 0.34^{cd}

L^*: lightness; a^*: redness-greenness; b^*: yellowness-blueness; L^*_{24h}, a^*_{24h} and b^*_{24h}: L^*, a^* and b^* values measured at 24 h after fresh noodle making; ΔL^*: L*0 h- L*24 h.
Flour: Hard red winter flour; GTE: green tea extract powder; BTE: black tea extract powder; OTE: oolong tea extract powder; Control: noodles without tea extracts; 0.5%, 1.0%, and 2.0% GTE: noodles with additional 0.5%, 1.0%, and 2.0% green tea extract, respectively; 0.5%, 1.0%, and 2.0% BTE: noodles with additional 0.5%, 1.0%, and 2.0% black tea extract, respectively; 0.5%, 1.0%, and 2.0% OTE: noodles with additional 0.5%, 1.0%, and 2.0% oolong tea extract, respectively; All additional levels were on a flour basis.
Results are presented as means ± standard deviations (n = 8 for fresh noodles). Means with different small letter superscripts in the same column are significantly different at $P < 0.05$.

Table 3
Color of dry Chinese white salted noodles with different tea extracts.

Sample	Dry Noodle powder		
	L*	a*	b*
Control	89.79 ± 0.37^{h}	−1.71 ± 0.02^{b}	9.49 ± 0.04^{b}
0.5% GTE	86.35 ± 0.16^{g}	−1.08 ± 0.02^{c}	11.25 ± 0.08^{c}
1.0% GTE	84.26 ± 0.34^{f}	−0.69 ± 0.01^{d}	15.64 ± 0.30^{f}
2.0% GTE	83.84 ± 0.06^{f}	−0.61 ± 0.00^{e}	15.92 ± 0.19^{g}
0.5% BTE	80.98 ± 0.45^{c}	1.41 ± 0.01^{h}	13.40 ± 0.05^{h}
1.0% BTE	76.37 ± 0.27^{a}	2.89 ± 0.01^{j}	16.09 ± 0.04^{j}
2.0% BTE	72.85 ± 0.81^{e}	4.27 ± 0.00^{f}	17.77 ± 0.08^{d}
0.5% OTE	82.46 ± 0.11^{d}	0.79 ± 0.01^{g}	13.04 ± 0.02^{e}
1.0% OTE	78.66 ± 0.34^{b}	1.88 ± 0.04^{i}	15.14 ± 0.16^{i}
2.0%OTE	74.14 ± 0.12^{i}	3.06 ± 0.03^{a}	16.97 ± 0.21^{a}

L*: lightness; a*: redness-greenness; b*: yellowness-blueness.
Control: noodles without tea extracts; 0.5%, 1.0%, and 2.0% GTE: noodles with additional 0.5%, 1.0%, and 2.0% green tea extract, respectively; 0.5%, 1.0%, and 2.0% BTE: noodles with additional 0.5%, 1.0%, and 2.0% black tea extract, respectively; 0.5%, 1.0%, and 2.0% OTE: noodles with additional 0.5%, 1.0%, and 2.0% oolong tea extract, respectively; All additional levels were on a flour basis.
Results are presented as means ± standard deviations (n = 2 for dry noodle powder and raw material powder). Means with different small letter superscripts in the same column are significantly different at $P < 0.05$.

Compared to the fresh WSN, an increase of the initial L* value was observed on the resulting dried noodles, which was caused by the inhibition of polyphenol oxidase (PPO) activity at a higher temperature and the reduction of water activity during the drying process. Drying resulted in an increase of a* value and decrease of b* value for the control noodles but a simultaneous decrease of a* and b* values for noodles incorporated with tea extracts. TPs might form new compounds through degradation, oxidation, epimerization, and polymerization reactions (Sharma & Zhou, 2011), which explained the less red and yellow appearance.

3.3. Cooking yield and textural properties

3.3.1. Noodle cooking yield

The cooking yield was 147.5% for control noodle, and it was decreased to 140.5%–145.5% for 0.5%–2.0% GTE addition, 141.0%–142.0% for BTE addition, and 143.5%–148.0% for OTE addition (Table 4). Cooking yield is mainly determined by the water absorption in starch gelatinization and gluten formation (Niu, Hou, Kindelspire, Krishnan, & Zhao, 2016). The water competition effect between hydroxyl groups of TPs and starch was responsible for the decrease of the cooking yield. Meanwhile, the net charge of the secondary and tertiary structure of protein molecules was influenced when being supplemented with TPs, which resulted in the change of hydrophilic/hydrophobic properties on protein surface and the solubility behavior.

3.3.2. Textural properties of cooked noodles

In Table 4, for GTE and OTE, hardness, chewiness and resilience were decreased at 0.5% and 1.0% levels, but were increased to similar values at 0.0% or 0.5% levels after decreasing at 2.0% level. Likewise, hardness and chewiness showed the same trend from 0.5% to 2.0% level for BTE. However, resilience of cooked noodles added with BTE were lower compared to GTE and OTE, and no significant differences were found between three levels. Tea extracts showed no significant effect on the adhesiveness of cooked WSNs except for 0.5% BTE.

Noodle hardness is determined by the strength of the gluten network and starch pasting properties. Chewiness and resilience values have high correlations with the overall gluten network, which provides viscoelasticity of the dough system (Niu et al., 2016). According to Mixolab results, tea extracts yielded less weakening of gluten strength during mixing. Higher peak viscosity generally has a negative relationship with noodle hardness (Wang, Hou, Hsu, & Zhou, 2011). It can be speculated that the softer texture of cooked noodles was primarily caused by the higher starch pasting viscosity at lower addition levels. Meanwhile, TPs are a series of reducing agents, which may interchange with the SS bond of proteins to form SH groups resulting in lower dough strength during the development of the gluten network. At 2.0% addition level, the hardness, chewiness, and resilience increased, which could be attributed to the covalent and non-covalent interactions that existed in a protein-polyphenol system. Compared to GTE and OTE, resilience showed the larger decrease with BTE but less difference was observed with 0.5%–2.0% BTE. The results indicated the lower strength of the cooked noodle with BTE regardless of addition level. The gluten properties that affecting noodle textual parameters are different from the Mixolab results. The discrepancy between dough and noodle strength might be caused by the different available water content for a series of structure changes of starch and protein in different systems.

3.4. Antioxidant capacity and starch digestibility

3.4.1. Antioxidant capacity

In Fig. 2, the results showed that tea extracts enhanced antioxidant properties of dry Chinese WSN. A negative correlation was found between total phenolic content (TPC) and IC_{50} value in dried noodles. R^2 was 0.8704, 0.6552 for BTE and 0.8199 for GTE, BTE and OTE, respectively. The improved antioxidant properties of the tea noodles were due to the incorporation of phenolic compounds from the tea extracts.

GTE contained the highest level of total phenolic component but

Table 4
Cooking yield and texture of cooked dry Chinese white salted noodle with different tea extracts.

Sample	Cooking yield (%)	Hardness (N)	Adhesiveness (N.sec)	Chewiness (N)	Resilience
Control	147.5 ± 2.1^{ef}	15.23 ± 0.25^{e}	−0.293 ± 0.008 ^{bc}	9.02 ± 0.15^{f}	0.316 ± 0.003^{cd}
0.5% GTE	140.5 ± 0.7^{a}	14.26 ± 0.34^{cd}	−0.313 ± 0.031^{ab}	8.16 ± 0.10^{cd}	0.298 ± 0.013^{abcd}
1.0% GTE	145.5 ± 2.1^{ef}	13.65 ± 0.18^{ab}	−0.307 ± 0.012^{b}	7.54 ± 0.05^{a}	0.281 ± 0.004^{ab}
2.0% GTE	145.0 ± 0.0^{de}	13.95 ± 0.35^{abc}	−0.296 ± 0.025^{bc}	8.25 ± 0.02^{cd}	0.319 ± 0.009^{d}
0.5% BTE	141.0 ± 0.0^{ab}	14.45 ± 0.11^{cd}	−0.355 ± 0.025^{a}	8.11 ± 0.13^{cd}	0.271 ± 0.022^{a}
1.0% BTE	142.0 ± 0.0^{ab}	13.47 ± 0.35^{a}	−0.299 ± 0.005^{bc}	7.46 ± 0.35^{a}	0.282 ± 0.005^{ab}
2.0% BTE	143.0 ± 0.0^{abc}	14.08 ± 0.17^{bcd}	−0.301 ± 0.031^{bc}	7.91 ± 0.04^{bc}	0.288 ± 0.006^{abc}
0.5% OTE	148.0 ± 1.4^{f}	14.56 ± 0.22^{d}	−0.301 ± 0.011^{bc}	8.41 ± 0.00 ^{d}	0.305 ± 0.001^{bcd}
1.0% OTE	143.5 ± 0.7^{bcd}	13.87 ± 0.12^{abc}	−0.253 ± 0.023^{c}	7.72 ± 0.04^{ab}	0.291 ± 0.013^{abcd}
2.0% OTE	144.0 ± 1.4^{cd}	14.05 ± 0.17^{abcd}	−0.286 ± 0.008^{bc}	8.10 ± 0.18^{cd}	0.307 ± 0.022^{bcd}

Control: noodles without tea extracts; 0.5%, 1.0%, and 2.0% GTE: noodles with additional 0.5%, 1.0%, and 2.0% green tea extract, respectively; 0.5%, 1.0%, and 2.0% BTE: noodles with additional 0.5%, 1.0%, and 2.0% black tea extract, respectively; 0.5%, 1.0%, and 2.0% OTE: noodles with additional 0.5%, 1.0%, and 2.0% oolong tea extract, respectively; All addition levels were on a flour basis.
Results are presented as means ± standard deviations (n = 4). Means with different small letter superscripts in the same column are significantly different at $P < 0.05$.

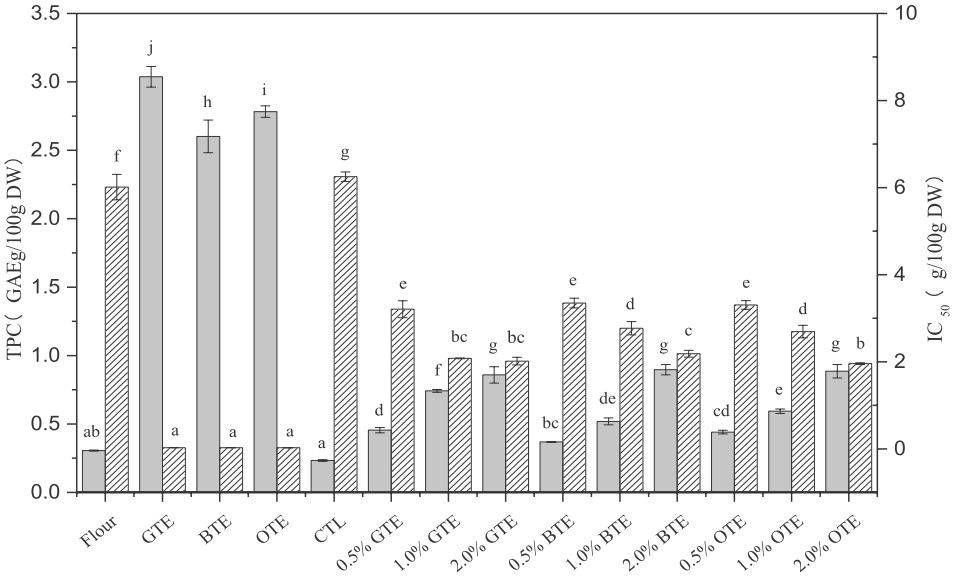

Fig. 2. Antioxidant capacity and total phenolic content of noodles with different tea extracts. Flour: Hard red winter flour (HRW); GTE: green tea extract; BTE: black tea extract; OTE: oolong tea extract; CTL: control noodles without tea extracts; 0.5%, 1.0%, and 2.0% GTE: noodles with additional 0.5%, 1.0%, and 2.0% green tea extract, respectively; 0.5%, 1.0%, and 2.0% BTE: noodles with additional 0.5%, 1.0%, and 2.0% black tea extract, respectively; 0.5%, 1.0%, and 2.0% OTE: noodles with additional 0.5%, 1.0%, and 2.0% oolong tea extract, respectively; All addition levels were on a flour basis. TPC: Total phenolic content; IC50: the effective concentration at which the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals were scavenged by 50%. Different letters indicate significant differences between groups ($p < 0.05$). TPC content; IC_{50} value.

showed similar antioxidant ability to BTE and OTE in the study. This result was in accordance with the findings reported by Leung et al. (2001) that TFs in black tea maintains at least the same antioxidant ability as do catechins in green tea and the oxidation of the latter to TFs does not significantly alter their free radical-scavenging activities. Additionally, the tea cultivar resources and the processing methods are also responsible for the antioxidant potency of tea extracts.

Control noodles also possessed a certain antioxidant activity due to the endogenous phenolic compounds. At 0.5% and 1.0% addition levels, noodles incorporated with GTE showed a higher TPC and antioxidant capacity than with BTE and OTE. When the level was up to 2.0%, for TPC and antioxidant capacity, GTE showed a slight increase, but BTE and OTE addition resulted in a significant ($p < 0.5$) increase. The results may be due to the interactions between catechins contained mostly in GTE and macromolecules in flour. Additionally, the DPPH, which was used for the evaluation of antioxidant capacity of the tea extracts, had a fixed number in the test system, so a 2.0% addition of GTE did not show stronger antioxidant capacity.

3.4.2. *In-vitro* starch digestibility

In Table 5, the GTE and BTE had non-significant changes in RDS but a significant decrease in SDS and a sharp increase in RS of noodle samples. However, no significant difference was observed among the studied addition levels (0.5%–2.0%). Similar results were found with OTE-enriched noodles, but a significant change was found among different levels especially for RS. The decrease in SDS ranged from 19.12% to 30.44% for GTE, 27.71%–43.20% for BTE, and 23.96%–39.47% for OTE. The RS content ranged from 0.64 g/100 g (dry weight) for the control to 8.87–12.89 g/100 g (dry weight), 11.58–15.15 g/100 g (dry weight), and 9.23–18.48 g/100 g (dry weight) for 0.5–2.0% addition of GTE, BTE, and OTE, respectively.

Control noodles showed the highest pGI values (91.12). The calculated pGI values of noodles incorporated with GTE ranged from 84.25 to 81.39; noodles incorporated with BTE ranged from 81.98 to 79.01; and noodles incorporated with OTE ranged from 83.94 to 76.23. Except for OTE, the level of each tea extract did not significantly affect the pGI.

Based on these results, tea extracts exhibited an excellent inhibition effect on *in-vitro* starch hydrolysis. On one hand, an inclusion complex was probably formed between TPs and amylose by hydrophobic interaction (Chai, Wang, & Zhang, 2013). The formed structure was less susceptible to enzyme digestion, which can explain the increase in the RS content in noodles incorporated with tea extracts. On the other hand, the hydrogen bonds formed between the hydroxyl groups of TPs and the catalytic residues of the binding site of the digestive enzymes

Table 5
RDS, SDS, RS contents and pGI of dried noodles with different tea extracts.

Sample	Starch fraction			pGI
	RDS (g/100 g dry weight)	SDS (g/100 g dry weight)	RS (g/100 g dry weight)	
Control	61.51 ± 1.56^{ab}	37.85 ± 1.34^{f}	0.64 ± 0.30^{a}	91.12 ± 0.25^{d}
0.5% GTE	61.19 ± 0.89^{ab}	29.49 ± 4.18^{cd}	9.32 ± 4.39^{b}	83.87 ± 3.66^{c}
1.0% GTE	60.52 ± 1.85^{ab}	30.61 ± 1.92^{d}	8.87 ± 2.31^{b}	84.25 ± 1.93^{c}
2.0% GTE	61.37 ± 1.03^{ab}	26.33 ± 1.33^{abcd}	12.29 ± 0.54^{bc}	81.39 ± 0.45^{bc}
0.5% BTE	61.06 ± 2.94^{ab}	27.36 ± 1.88^{bcd}	11.58 ± 1.92^{bc}	81.98 ± 1.60^{bc}
1.0% BTE	63.35 ± 2.56^{b}	21.50 ± 4.64^{a}	15.15 ± 2.54^{cd}	79.01 ± 2.12^{ab}
2.0% BTE	59.68 ± 2.12^{ab}	25.18 ± 3.07^{abcd}	15.13 ± 0.95^{cd}	79.02 ± 0.80^{ab}
0.5% OTE	61.99 ± 1.81^{ab}	28.78 ± 2.16^{cd}	9.23 ± 2.63^{b}	83.94 ± 2.20^{c}
1.0% OTE	60.92 ± 0.76^{ab}	24.09 ± 0.48^{abc}	14.99 ± 0.29^{cd}	79.14 ± 0.24^{ab}
2.0% OTE	58.61 ± 1.96^{a}	22.91 ± 4.52^{ab}	18.48 ± 3.08^{e}	76.23 ± 2.58^{a}

RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch; pGI: predicted glycemic index.
Control: noodles without tea extracts; 0.5%, 1.0%, and 2.0% GTE: noodles with additional 0.5%, 1.0%, and 2.0% green tea extract, respectively; 0.5%, 1.0%, and 2.0% BTE: noodles with additional 0.5%, 1.0%, and 2.0% black tea extract, respectively; 0.5%, 1.0%, and 2.0% OTE: noodles with additional 0.5%, 1.0%, and 2.0% oolong tea extract, respectively; All addition levels were on a flour basis.
Results are presented as means ± standard deviations (n = 3). Means with different small letter superscripts in the same column are significantly different at $P < 0.05$.

and formation of a conjugated л-system that stabilized the interaction with the active site inhibited the enzyme activity (Miao, Jiang, Jiang, Zhang, & Li, 2015). Koh, Wong, Loo, Kasapis, and Huang (2010) reported the galloyl moiety played an essential role in determining the digestion inhibition effect. Therefore, BTE and OTE, which may provide many more gallic compounds as a polymerized form than GTE, consequently appeared to exhibit a stronger inhibition effect.

4. Conclusions

This study investigated the effects of incorporating GTE, BTE, and OTE into traditional dry Chinese white salted noodles. The tea extracts improved dough strength and promoted starch gelatinization in the Mixolab test. The addition of tea extracts increased darkness, decreased hardness and chewiness, but had little effect on cooking yield, cohesiveness, and resilience of noodles. However, antioxidant capacity results showed that all samples were characterized with significantly higher radicals scavenging abilities compared to the control. Digestion analysis reflected redistribution of starch components (reduction of SDS and increase of RS) and lowered the predicted GI. In commercial noodle production, 1–2% of tea extract could be added in dry noodle formulation to significantly improve its health benefits without significantly affecting its noodle texture.

Declarations of interest

None.

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