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Computational and experimental investigations on the influence of different factors on the content of phenolic compounds from selected tea samples

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Abstract

Aqueous solutions of four commercial types of tea: black, green, sour cherry, and raspberry, were investigated experimentally and computationally, on the influence of different factors on the content of phenolic compounds. For black tea, it is good to keep tea for 14.5 min at 73.6°C, 80°C and 12.9 min for green tea, 69.7°C and 16.2 min for sour cherry tea, and 74°C and 14.5 min for raspberry tea. During storage, when tea bags of black and green teas were kept at 4, 25, and 35°C, the maximal value of total flavonoids was observed at the 40th day (except for green tea at 35°C, when it was observed at the 50th day).

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Introduction

The use of tea as a soft hot drink began 5,000 years ago (Gutman and Ryu, 1996). Tea came to Europe in 1610 by a Dutch ship, although it has been consumed as early as 1560 by Jesuit Father Jasper de Cru according to a written document (Sartor, 2007). Americans contributed to tea science by inventing tea bags (Bassi *et al.*, 2019).

Nowadays, tea is the second most consumed drink worldwide (de Almeida *et al.*, 2019). There are three large tea groups with different uses: (1) those obtained from the tea plant (*Camellia sinensis* (L.) Kuntze) (Chan *et al.*, 2011); (2) those obtained from different medicinal plants (herbal teas); and (3) those obtained from flowers, seeds, and fruit peels. Green and black teas are processed differently during manufacturing. Green tea is made by inactivating the enzymes in the fresh leaves of tea (*C. sinensis* (L.) Kuntze), either by firing or steaming, thus preventing the enzymatic oxidation of catechins (Wang *et al.*, 2000). Black tea is made by a polyphenol oxidase catalysed oxidation of fresh leaf catechins (fermentation process) (Wang *et al.*, 2000).

Tea and herbal infusions represent one of the significant sources of phenolics in the human diet (Dimitrios, 2006). Major flavonoids in teas are very well-investigated and well-known (Kanwar *et al.*, 2012; Stodt and Engelhardt, 2013; Veljković *et al.*, 2013; Yashin *et al.*, 2015). The strong antioxidant nature of tea polyphenols is attributed to their phenolic hydroxyl structure in which the electrons have a conjugation effect. Catechin and other polyphenols act as antioxidants *in vitro* by sequestering metal ions, and scavenging reactive oxygen and nitrogen species (Kanwar *et al.*, 2012). Also, tea polyphenols were documented to prevent and treat various diseases. Epidemiological studies suggest a correlation between tea consumption and reduced risk of type 2 diabetes, and beneficial effects on cardiovascular and metabolic health and immunity (Yan *et al.*, 2020).

The investigation of the influence of time and temperature on the content of total flavonoids in teas was performed earlier to a limited extent (Wang *et al.*, 2000; Ligor *et al.*, 2008), and UHPLC and HPLC analyses in the investigation of storage time on phenolic compounds present (Silarova *et al.*, 2017;

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Zhou *et al.*, 2020; Zheng *et al.*, 2021). The degradation of flavonoids upon heating, evidenced through the decrease in values, was investigated extensively (Song *et al.*, 2015; Snoussi *et al.*, 2022). Previously, the effect of temperature and time was studied on selected teas from the black, green, and white tea classes in a very small number of cases (Hajiaghaalipour *et al.*, 2016). White tea was the subject of one more study on the effect of temperature and time on antioxidant capacity and total phenols (Perez-Burillo *et al.*, 2018).

The present work thus aimed to perform the extraction of flavonoids from four types of teas, and determine computationally through the obtained models on the optimal conditions for the extraction of flavonoids. Also, the effect of storage, time, and temperature was investigated on the contents of detected phenolic compounds in studied teas (black, green, raspberry, and cherry). To the best of our knowledge, nobody before us investigated the influence of specified values of time and temperature on the content of flavonoids in the studied herbal teas. There are published studies, however, on the influence of time and temperature on the antioxidant properties, sensory attributes, and metabolic profiles of some black, white, Oolong, and green teas (Wang and Xu, 2014; Castiglioni *et al.*, 2015; Perez-Burrilo *et al.*, 2018; Jin *et al.*, 2019).

The obtained results can be useful for the storage management of different types of teas, and the recommendations for the best results for the extractions of flavonoids from teas. The obtained results can also be applied in the food industry to achieve the best results in flavonoid extraction, and for tea consumers to get the best health benefits from drinking tea.

Materials and methods

Chemicals

Sodium hydroxide, sodium nitrite, and aluminium chloride hexahydrate were purchased from Merck® (Darmstadt, Germany). Standards of phenolic compounds: gallic acid (J & K Scientific, Chaoyang District Beijing, China), protocatechuic acid (Roth, Karlsruhe, Germany), caffeic acid (Sigma), procyanidin B2 (Fluka), (+)-catechin (Sigma-Aldrich, St. Louis, MO, USA), (-)-epicatechin (Sigma-Aldrich, St. Louis, MO, USA), rutin (Merck®, KGaA, Darmstadt, Germany), morin (Merck®, KGaA, Darmstadt, Germany), quercetin (Sigma-Aldrich, St. Louis, MO, USA), and delphinidin-3-*O*-sambubioside and cyanidin-3-*O*-sambubioside were obtained from Sigma-Aldrich (St. Louis, MO, USA). Formic acid and acetonitrile were of HPLC-grade, and obtained from J. T. Baker®.

Instruments

An Agilent 8453 UV/Vis spectrophotometer (Agilent Technologies, Santa Clara, California, USA) was used for absorbance measurements and spectra recording, using optical cuvettes of a 1 cm optical path. Deionised water (0.05 µS/cm) was obtained from the MicroMed high-purity water system (TKA Wasseraufbereitungssysteme GmbH).

An HPLC Agilent-1200 series with UV-Vis DAD (Agilent Technologies, Santa Clara, California, USA) was used for multiwavelength and fluorescence detection for the acquisition of the emission response.

pH of teas from tea bags was measured using a pH meter (Hanna Instruments, USA) previously calibrated using buffer solutions (pH 4.00 and 7.00).

Samples

The tea bags used for the investigation were green tea (*C sinensis* (L.) Kuntze), black tea (*C. sinensis* (L.) Kuntze), cherry tea (*Prunus cerasus* L.), and raspberry tea (*Rubus idaeus* L. 1753, not Blanco 1837 nor Vell. 1829 nor Pursh 1814 nor Thunb. 1784). Tea bags of green and black teas contained leaves. Cherry tea bags had cherry aroma, hibiscus flower, apple fruit, rose hip fruit, orange peel, and elderberry. Raspberry tea bags contained raspberry aroma and black tea.

Effect of steeping time and temperature on total flavonoid content

The plant material was taken from the tea bags and ground using a mortar and pestle. Then, 1 g was weighed (the precision on the 4th decimal place) from each tea sample. The weighed tea sample was poured with 80 mL water at temperatures 60, 70, 80, 90, and 100°C, and steeped for 5, 10, 15, and 20 min. The samples were filtered through cotton wool into a volumetric flask (100 mL), and filled with deionised water up to the mark.

Effect of steeping time and temperature on selected phenolic compounds contents

The plant material was taken from the tea bags and ground using a mortar and pestle. Then, 1 g was weighed accurately from each tea sample. The weighed tea sample was poured with 80 mL water at temperatures 60, 70, 80, 90, and 100°C, and steeped for 5, 10, 15, and 20 min. The samples were filtered through cotton wool into a volumetric flask (100 mL), and filled with deionised water up to the mark.

Effect of storage time and temperature on total flavonoid content

From the tea bags kept in the fridge, at room temperature (25°C), and 35°C, at different storage times (10, 20, 30, 40, and 50 days) after the tea boxes opening, the plant material was taken and well ground using mortar and pestle. 1 g was weighed accurately, poured with 80 mL deionised water at the temperature 100°C, and after 10 min, the sample was filtered through cotton wool into the volumetric flask (100 mL), and filled with deionised water up to the mark.

Effect of storage time and temperature on selected phenolic compounds contents

From the tea bags kept in the fridge, at room temperature (25°C), and 35°C, at different storage times (10, 20, 30, 40, and 50 days) after the tea boxes opening, the plant material was taken and well ground using mortar and pestle. 1 g was weighed accurately, poured with 80 mL deionised water at the temperature 100°C, and after 10 min, the sample was filtered through cotton wool into the volumetric flask (100 mL) and filled with deionised water up to the mark.

Determination of total flavonoids

The content of total flavonoids was determined spectrophotometrically using $AlCl_3$ (Yang *et al.*, 2007). The reaction mixture was prepared using 0.25 mL of the sample, 3 mL of deionised water, and 0.3 mL of 5% $NaNO_2$. After 5 min, 3 mL of $AlCl_3$ was added, and then after, 2 mL of NaOH and deionised water to 10 mL. Absorption was measured at 510 nm. Based on the absorbance using the calibration curve, the concentration (mg/mL) of total flavonoids in the extracts was determined. Flavonoid content was expressed as a milligram equivalent of catechin per gram of the tea (mg CE/g).

HPLC analysis of selected phenolic compounds

The equipment used was an HPLC Agilent-1200 series with UV-Vis DAD for multi-wavelength detection and fluorescence detection for the acquisition of the emission response. The column was thermostated at 30°C. After injecting 5 μL of the sample, the separation was performed in an Agilent 5 μm ZORBAX Eclipse XDB-C18 4.6 · 150 mm column. Two solvents were used for the gradient elution = A: H_2O + 5% HCOOH, and B: 80% ACN + 5% HCOOH + H_2O. The elution program used was as follows: from 0 to 10 min, 0% B; from 10 to 28 min, gradually increased 0 - 25% B; from 28 to 30 min, 25% B; from 30 to 35 min, gradually increased 25 - 50% B; from 35 to 40 min, gradually increased 50 - 80% B; and finally for the last 5 min, gradually decreased 80 - 0% B (Mitic *et al.*, 2012). All quantifications were carried out with external standards. The identification of individual compounds was based on the retention times of the original standards, where available, and spectral data. Monitoring of the eluate was performed at 520 nm for the identification of anthocyanins, 360 nm for the identification of flavonols, and 280 nm for the identification of phenolic acids. Flavan-3-ols were monitored at 275/322 nm ($\lambda_{Ex}/\lambda_{Em}$) with a fluorescence detector. The results were expressed as mg/g dry weight.

Full factorial design

Full factorial design for each investigated tea sample was performed using full factorial design in JMP® Trial 16.2.0 (SAS Institute Inc., USA). The value of total flavonoids was set to reach the target, and the steeping temperature and duration (in the first case) and storage temperature and duration (in the second case) were used as factors.

Results and discussion

Investigated aqueous solutions of teas from tea bags showed similar pH values = black tea, 5.18; green tea, 5.54; sour cherry, 4.80; and raspberry, 5.05. Tea polyphenols are pH-sensitive, but at 4 and 25°C they were shown to remain stable at pH of 3 - 6 (Zeng *et al.*, 2017). pH of teas is very important in the analysis of biologically active forms of compounds responsible for the health effects of these aqueous solutions. The stability of phenolic compounds strongly depends not only on the pH of the buffers and storage time, but also on the structure of the phenolic compound (Friedman and Jurgens, 2000).

Effect of steeping time and temperature on total flavonoid content

The influence of steeping time and temperature on total flavonoid content was assessed at 5, 10, 15, and 20 min, and 60, 70, 80, 90, and 100°C (Table 1).

Table 1. Total flavonoid contents (mgCE/g) in black, green, cherry, and raspberry teas based on steeping temperature and duration.

Duration	Tea	60°C		70°C		80°C		90°C		100°C	
		c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
5 min	Black	18.08 ± 0.77	4.26	20.81 ± 0.71	3.41	22.92 ± 1.47	6.41	29.75 ± 0.47	1.58	31.98 ± 1.41	4.41
	Green	37.64 ± 1.00	2.66	39.09 ± 0.56	1.43	41.63 ± 0.94	2.28	45.68 ± 1.01	2.21	45.56 ± 0.00	0.00
	Sour cherry	28.79 ± 0.38	1.32	32.00 ± 0.36	1.12	33.77 ± 2.17	6.43	34.22 ± 0.35	1.02	35.32 ± 0.38	1.08
	Raspberry	28.48 ± 0.00	0.00	31.61 ± 1.44	4.56	39.26 ± 0.48	1.22	40.44 ± 0.47	1.16	43.88 ± 0.51	1.16
10 min	Black	26.85 ± 1.65	6.14	26.12 ± 0.78	2.98	29.19 ± 0.81	2.77	32.68 ± 0.72	2.20	37.23 ± 0.00	0.00
	Green	47.31 ± 0.53	1.12	41.92 ± 0.03	0.07	43.12 ± 0.46	1.07	45.10 ± 0.94	2.08	46.65 ± 0.46	0.98
	Sour cherry	30.15 ± 1.07	3.55	36.14 ± 0.37	1.02	38.43 ± 0.38	0.99	35.35 ± 0.35	0.99	36.84 ± 0.36	0.97
	Raspberry	31.14 ± 0.94	3.02	34.74 ± 0.98	2.82	41.54 ± 0.49	1.18	35.06 ± 0.76	2.17	45.54 ± 0.96	2.11
15 min	Black	28.65 ± 0.79	2.76	43.49 ± 0.46	1.06	32.25 ± 1.47	4.56	29.18 ± 0.78	2.67	39.46 ± 0.78	1.98
	Green	53.30 ± 0.56	1.05	43.02 ± 0.37	0.86	47.75 ± 0.92	1.93	46.45 ± 0.39	0.84	48.03 ± 0.93	1.94
	Sour cherry	33.10 ± 1.07	3.23	41.79 ± 1.19	2.84	39.07 ± 0.36	0.92	43.11 ± 0.72	1.67	43.59 ± 0.72	1.65
	Raspberry	36.92 ± 0.95	2.57	36.14 ± 0.96	2.66	42.30 ± 0.48	1.13	41.51 ± 0.49	1.18	46.41 ± 0.00	0.00
20 min	Black	33.47 ± 2.32	6.93	38.96 ± 0.84	2.16	37.36 ± 0.76	2.03	35.08 ± 1.51	4.30	47.15 ± 1.62	3.44
	Green	54.58 ± 1.03	1.89	45.88 ± 1.38	3.01	49.44 ± 0.91	1.84	48.37 ± 0.46	0.95	50.19 ± 0.00	0.00
	Sour cherry	34.81 ± 0.70	2.01	43.02 ± 0.37	0.86	42.29 ± 0.36	0.86	36.99 ± 0.35	0.95	45.09 ± 0.36	0.80
	Raspberry	40.11 ± 0.44	1.10	39.71 ± 0.98	2.47	43.44 ± 0.47	1.08	41.63 ± 0.47	1.13	49.53 ± 0.94	1.90

These values were chosen based on usual practice in preparing tea infusions.

When the tea bag was steeped for 5 min at 60°C, the total flavonoid content was 18.08 mgCE/g, and then with the increase in temperature, this increased and reached the value of 31.98 mgCE/g at 100°C for black tea. A similar trend was observed when black tea was steeped for 10 min: the content of total flavonoids went from 26.85 mgCE/g at 60°C to 37.23 mgCE/g at 100°C. In the case of 15 min, the maximal value was observed at 70°C (43.49 mgCE/g) for black tea. This value was not achieved when black tea was steeped for 20 min, except at 100°C, when the value of 47.15 mgCE/g was observed. For green tea, the content of total flavonoids was higher at 60°C for 5 min compared to black tea of 37.64 mgCE/g. For 10 min, the maximal content of total flavonoids for green tea at 60°C was 47.31 mgCE/g, and a similar situation was observed for 15 min (53.30 mgCE/g) and 20 min (54.58 mgCE/g). Fruit teas - sour cherry and raspberry, showed similar behaviour: minimal values of total flavonoids for 5 min were observed at 60°C (28.79 mgCE/g for sour cherry and 28.48 mgCE/g for raspberry), and maximal values at 100°C (35.32 mgCE/g for sour cherry and 43.88 mgCE/g for raspberry). However, for 10 min, they showed different behaviour: maximal values for the content of total flavonoids at 80°C for sour cherry was 38.43 mgCE/g, and at 100°C for raspberry was 45.54 mgCE/g. Similar behaviour was observed for 15 and 20 min, with no simple trends in the values for total flavonoids. The data showed that extraction dominated at lower temperatures (an increase in the value of total flavonoids), followed by degradation (a decrease in the value of the content of total flavonoids). Tea polyphenol (-)-epigallocatechin-3-gallate stability has been investigated, and it was found that its stability would be affected by its physical state, the concentration of reactants, oxygen levels, pH, and relative humidity (Li *et al.*, 2013). Tea catechins are the most vulnerable to oxidation, epimerisation, degradation, and polymerisation upon heating (Ananingsih *et al.*, 2013). Epimerisation and degradation of tea catechins follow the first-order kinetics (Wang *et al.*, 2008). Different behaviour of green tea compared to other investigated tea samples (black, sour cherry, and raspberry tea) was expected because it was earlier found that two specific points exist for (–)-epigallocatechin gallate (EGCG), the most abundant catechin in green tea: 44 and 98°C, due to specific reactions (Wang *et al.*, 2008). The specific point for some of the investigated tea samples (black, green, sour cherry, and raspberry) with longer steeping time was 100°C (except raspberry tea, which occurred earlier), as reported before (Ananingsih *et al.*, 2013).

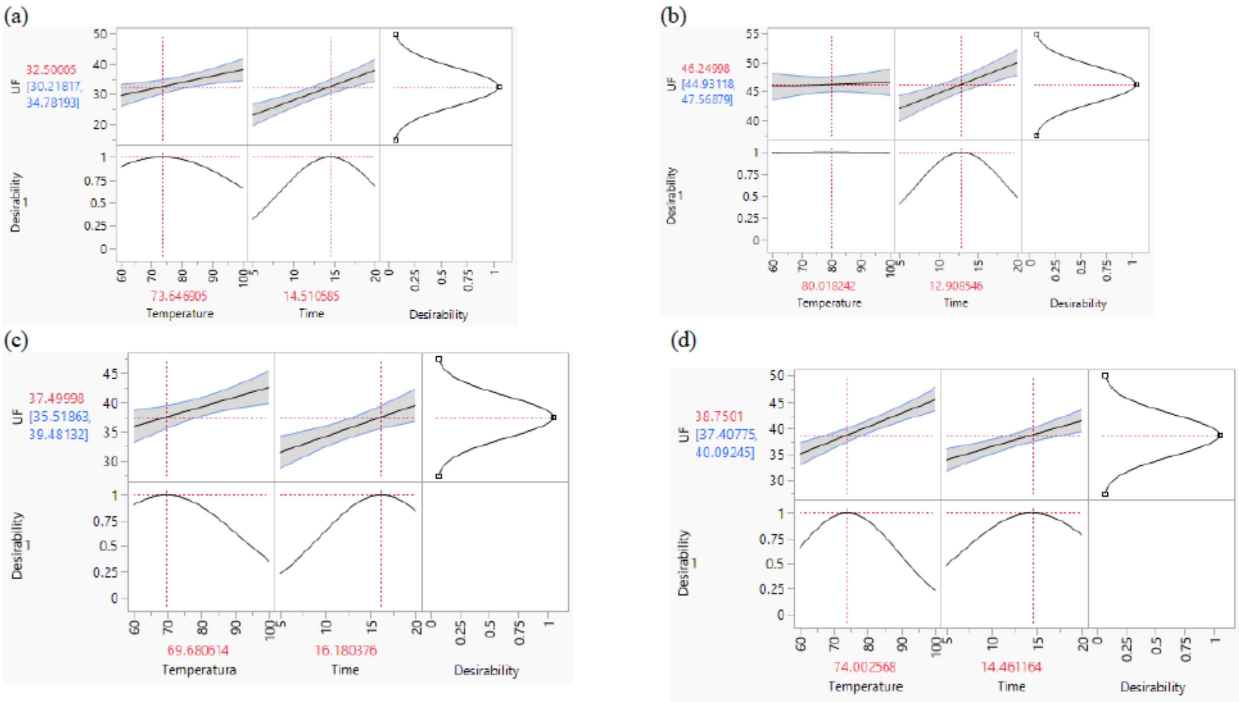
Response surface methodology (RSM) - full factorial design considering the time (5, 10, 15, and 20 min) and temperature of water (60, 70, 80, 90, and 100°C) (Figure 1A) was used to computationally find the optimum values of time and temperature for the extraction of flavonoids from each tea, where there is still a low degree of degradation. Previously, RSM was used in tea-related studies to estimate the optimal extraction time, extraction temperature, and their interactions among other parameters on instant sweet tea yield (Liu *et al.*, 2021).

For black tea ($p < 0.0001$), it is good to keep tea for 14.5 min at 73.6°C. For green tea ($p = 0.0008$), 80°C and 12.9 min. For sour cherry tea ($p = 0.0002$), 69.7°C and 16.2 min. For raspberry tea ($p < 0.0001$), 74°C and 14.5 min. Further heating and steeping would cause degradation, which was evident through the decrease of the values (Table 1). The degradation of flavonoids was previously found to follow a first-order reaction model in dark chocolate and myrtle samples (Wang *et al.*, 2008; Pavlovic *et al.*, 2017; Snoussi *et al.*, 2022).

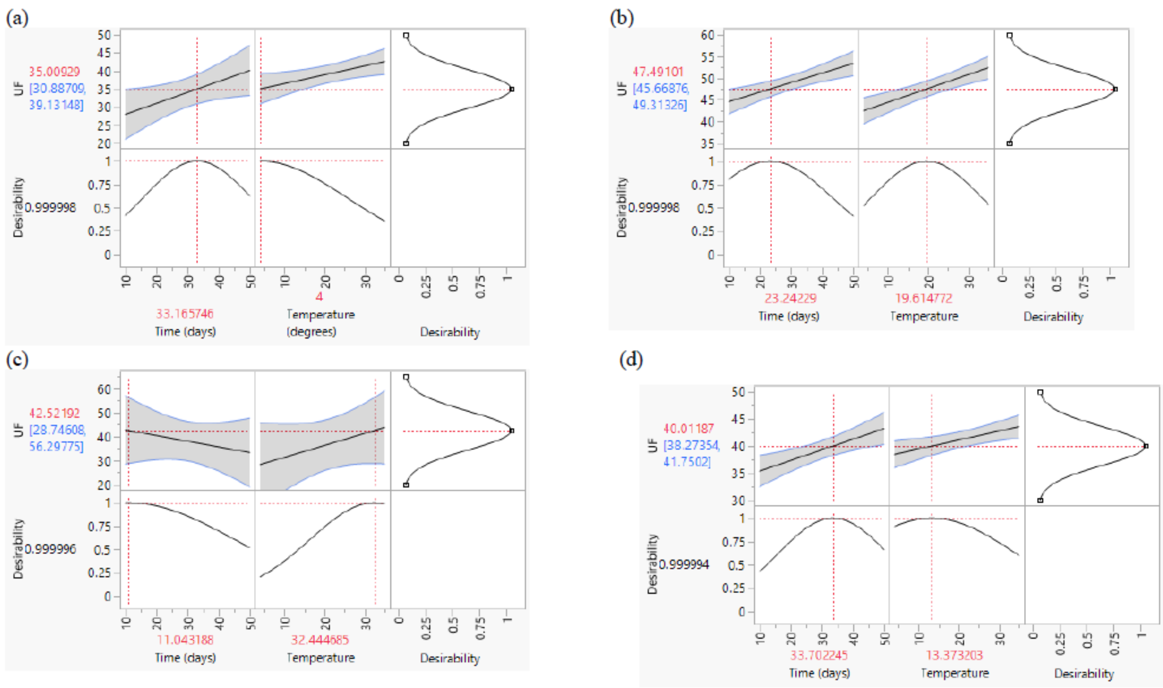
Effect of steeping time and temperature on selected phenolic compounds contents

Investigating the influence of time and temperature on the content of phenolic compounds is a prerequisite for the understanding of the nature of compounds present in foods and their interactions (Friedman and Jurgens, 2000). It was found that heating temperature had a significant effect on total phenolic content and total flavonoid content. In contrast, heating time did not have a significant effect on the phytochemicals and antioxidant activity in the case of garlic (Alide *et al.*, 2020).

There is a published research on the HPLC analysis of polyphenolic compounds in black tea, where among the determined catechins in fresh leaves, the most abundant was epigallocatechin gallate, followed by epigallocatechin, and epicatechin gallate (Wu *et al.*, 2021). They aimed to explore the effect of fermentation time and temperature on the content of polyphenolic compounds (Wu *et al.*, 2021). In our study, the content of seven phenolic



(A)



(B)

Figure 1. (A) Prediction profiler with maximum desirability (1) regarding steeping temperature and duration for: (a) black, (b) green, (c) sour cherry, and (d) raspberry teas. **(B)** Prediction profiler with maximum desirability (1) regarding storage temperature and duration for: (a) black, (b) green, (c) sour cherry, and (d) raspberry teas.

compounds was monitored during different durations and temperatures using HPLC DAD in black tea sample: gallic acid, caffeic acid, rutin, morin, quercetin, (+)-catechin, and procyanidin B1 (Table 2). The content of gallic acid in black tea showed an increasing trend, except in three cases (5 min, 80°C; 10 min, 70°C; and 20 min, 80°C). Caffeic acid, quercetin, and procyanidin B1 contents in black tea showed an increasing trend across all parameters. A very similar situation was seen for rutin (except at 15 min and 80°C) and morin (except at 10 min and 80°C).

Fruit teas available at the market in the United Kingdom were investigated for their catechins contents (Khokhar and Magnusdottir, 2002), and no catechin was detected. In our investigation, in the case of raspberry, eight compounds were quantified based on the available standards: gallic acid, caffeic acid, (+)-catechin, (-)-epicatechin, procyanidin B1, rutin, delphinidin-3-*O*-sambubioside, and cyanidin-3-*O*-sambubioside (Table 2). The content of gallic acid in raspberry tea showed an increasing trend, except in one case (10 min, 90°C). A similar trend was observed for caffeic acid with two exceptions (5 min, 100°C; and 15 min, 70°C). (+)-Catechin showed very unusual behaviour with some exceptions from the increasing trend (5 min at 80 and 90°C; 15 min at 90°C; and 20 min at 70°C) compared to quantified phenolic acids. (-)-Epicatechin showed similar behaviour to (+)-catechin, an increasing trend with some exceptions (5 min at 70°C; 15 min at 90°C; 20 min at 80°C; and 100°C). Procyanidin B1, similar to the observed trend in black tea, showed an increasing trend, except in the case of 5 min at 70°C, 10 min at 70°C and 100°C, 15 min at 90°C, and 20 min at 80°C. Different behaviour in raspberry of procyanidin B1 compared to black tea can be explained by different matrices, which obviously influenced its extraction and degradation processes. Rutin content increased with increasing temperature, except in the following cases: 5 min at 100°C; 15 min at 70°C; and 20 min at 70°C. Delphinidin-3-*O*-sambubioside was the most abundant phenolic compound, and its content increased with increasing temperature. Cyanidin-3-*O*-sambubioside content increased with increasing temperature except in the cases: 10 min at 70°C; 15 min at 80°C; and 20 min at 70°C.

In cherry tea, nine phenolic compounds were determined (Table 2): gallic acid, caffeic acid, (+)-catechin, (-)-epicatechin, (-)-epigallocatechin, procyanidin B2, procyanidin B3, delphinidin-3-*O*-sambubioside, and cyanidin-3-*O*-sambubioside. Gallic acid content increased with increasing temperature except in the following cases: 5 min at 100°C; 15 min at 90°C; and 20 min at 90°C. Caffeic acid showed even more irregular behaviour with increasing temperature: 5 min at 80 and 90°C; 20 min at 80°C; and 100°C. (+)-Catechin content also showed irregular trend with increasing temperature at 5 min at 80 and 90°C, 10 min at 90°C, 15 min at 90°C, and 20 min at 90°C. (-)-Epicatechin content showed deviation from the increasing trend at 5 min at 80°C; 10 min at 90°C; 15 min at 80°C; and 20 min at 90°C. Procyanidin B2 showed increasing trend in all cases with increasing temperature, except for 5 min at 80°C, and 15 min at 80°C. Procyanidin B3 content showed increasing trend in all cases with increasing temperature, except at 10 min at 80°C, 15 min at 100°C, and 20 min at 80°C. Delphinidin-3-*O*-sambubioside, similar to raspberry tea, was cherry's tea most abundant phenolic compound. At the same time, with the increase in temperature, the content of this compound increased in all cases. Cyanidin-3-*O*-sambubioside content increased with the temperature increase in all cases, except for 15 min at 80°C, and 20 min at 70°C.

In green tea, ten phenolic compounds were quantified (Table 2): gallic acid, protocatechuic acid, caffeic acid, rutin, morin, quercetin, (+)-catechin, (-)-epicatechin, procyanidin B2, and procyanidin B3. A different HPLC-based method was developed earlier to analyse gallic acid, caffeine, and five catechins in green tea using a C18 reversed-phase column (Theppakorn and Wongsakul, 2012). With the increase in temperature, the content of gallic acid increased, except in one case (20 min at 90°C). Protocatechuic acid content increased in all cases with the increase in temperature, except for 5 min at 90°C, 10 min at 80°C, 15 min at 80°C, and 20 min at 70°C. Caffeic acid content increased with the increase in temperature, except for 10 min at 80 and 90°C, 15 min at 70°C, and 20 min at 100°C. Rutin content increased with the increase in temperature, except in one case (15 min at 100°C). Morin content showed similar behaviour to rutin, except at 15 min at 90°C. Quercetin content increased with the increase in temperature, except for the following cases: 10 min at 100°C, 15 min at 70°C, and 20 min at 70°C. (+)-Catechin content increased with the increase in temperature, except in one case (10 min at 100°C).

Table 2. Total phenolic contents (mg/g) in black, green, cherry, and raspberry teas based on steeping temperature and duration.

Duration	Phenolic compound	Tea	60°C		70°C		80°C		90°C		100°C	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
5 min	Gallic acid	Black	0.39 ± 0.01	2.56	0.52 ± 0.01	1.92	0.41 ± 0.01	2.44	0.60 ± 0.01	1.67	0.78 ± 0.01	1.28
		Green	0.45 ± 0.01	2.22	1.12 ± 0.06	5.35	1.27 ± 0.06	4.72	1.94 ± 0.06	3.09	2.03 ± 0.07	3.45
		Sour cherry	0.397 ± 0.004	1.01	0.616 ± 0.004	0.65	0.634 ± 0.003	0.47	0.873 ± 0.002	0.23	n.d.	/
		Raspberry	1.26 ± 0.03	2.38	1.28 ± 0.03	2.34	1.29 ± 0.03	2.33	1.30 ± 0.04	3.08	1.39 ± 0.04	2.88
	Caffeic acid	Black	0.028 ± 0.001	3.57	0.037 ± 0.001	2.70	0.054 ± 0.001	1.85	0.061 ± 0.001	1.64	0.099 ± 0.001	1.01
		Green	0.021 ± 0.001	4.76	0.033 ± 0.001	3.03	0.045 ± 0.001	2.22	0.055 ± 0.001	1.82	0.061 ± 0.001	1.64
		Sour cherry	0.056 ± 0.001	1.79	0.086 ± 0.001	1.16	0.082 ± 0.001	1.23	n.d.	/	0.118 ± 0.002	1.69
		Raspberry	0.133 ± 0.002	1.50	0.138 ± 0.003	2.17	0.153 ± 0.003	1.96	0.156 ± 0.002	1.28	n.d.	/
	Protocatechuic acid	Green	0.39 ± 0.01	2.56	0.66 ± 0.01	1.51	0.94 ± 0.02	2.13	0.82 ± 0.02	2.44	1.21 ± 0.03	2.48
	Rutin	Black	0.47 ± 0.01	2.13	0.58 ± 0.01	1.72	0.65 ± 0.01	1.54	0.91 ± 0.01	1.10	1.19 ± 0.03	2.52
		Green	0.36 ± 0.01	2.78	0.49 ± 0.01	2.04	0.51 ± 0.01	1.96	0.52 ± 0.01	1.92	0.82 ± 0.01	1.22
		Raspberry	0.122 ± 0.002	1.64	0.198 ± 0.002	1.01	0.233 ± 0.002	0.86	0.253 ± 0.002	0.73	0.251 ± 0.002	0.80
	Morin	Black	0.18 ± 0.01	5.56	0.24 ± 0.01	4.17	0.39 ± 0.01	2.56	0.48 ± 0.01	2.08	0.62 ± 0.01	1.62
		Green	0.132 ± 0.004	3.03	0.64 ± 0.01	1.56	0.88 ± 0.01	1.14	1.08 ± 0.03	2.78	1.12 ± 0.04	3.57
	Quercetin	Black	0.99 ± 0.01	1.01	0.105 ± 0.001	0.95	0.132 ± 0.001	0.76	0.169 ± 0.001	0.59	0.24 ± 0.01	4.17
		Green	0.172 ± 0.003	1.74	0.38 ± 0.01	2.63	0.48 ± 0.01	2.08	0.55 ± 0.01	1.82	0.56 ± 0.01	1.78
	(+)-Catechin	Black	0.112 ± 0.003	2.68	0.132 ± 0.003	2.27	0.142 ± 0.003	2.11	0.143 ± 0.004	2.80	0.192 ± 0.003	1.56
		Green	0.066 ± 0.001	1.51	0.089 ± 0.001	1.12	0.131 ± 0.001	0.76	0.174 ± 0.002	1.15	0.23 ± 0.01	4.35
		Sour cherry	0.86 ± 0.02	2.33	1.41 ± 0.02	1.42	1.35 ± 0.02	1.48	1.35 ± 0.03	2.22	1.51 ± 0.02	1.32
		Raspberry	0.106 ± 0.002	1.87	0.118 ± 0.002	1.69	n.d.	/	0.112 ± 0.002	1.78	0.124 ± 0.002	1.61
	(-)-Epicatechin	Green	0.24 ± 0.01	4.17	0.37 ± 0.01	2.70	0.48 ± 0.01	2.08	0.72 ± 0.01	1.39	0.52 ± 0.01	1.92
		Sour cherry	0.184 ± 0.004	2.17	0.269 ± 0.004	1.49	0.265 ± 0.004	1.51	0.297 ± 0.003	1.01	0.308 ± 0.004	1.30
		Raspberry	0.154 ± 0.002	1.30	n.d.	/	0.266 ± 0.002	0.75	0.291 ± 0.003	1.03	0.352 ± 0.003	0.85
	(-)-Epigallocatechin	Sour cherry	0.042 ± 0.001	2.38	0.058 ± 0.001	1.72	0.093 ± 0.003	3.23	0.093 ± 0.002	2.15	0.097 ± 0.002	2.06
	Procyanidin B1	Black	0.111 ± 0.001	0.90	0.145 ± 0.001	0.69	0.154 ± 0.001	0.65	0.162 ± 0.001	0.52	0.186 ± 0.001	0.54
		Raspberry	0.104 ± 0.002	1.92	0.102 ± 0.002	1.96	0.124 ± 0.002	1.61	0.128 ± 0.002	1.56	0.129 ± 0.002	1.55
	Procyanidin B2	Green	0.046 ± 0.001	2.17	0.099 ± 0.001	1.01	0.128 ± 0.001	0.78	0.142 ± 0.001	0.70	0.46 ± 0.01	2.17
		Sour cherry	0.077 ± 0.002	2.59	0.120 ± 0.002	1.67	0.115 ± 0.003	2.61	0.153 ± 0.003	1.96	0.263 ± 0.003	1.14
	Procyanidin B3	Green	0.024 ± 0.001	4.17	0.044 ± 0.001	2.27	0.046 ± 0.001	2.17	0.056 ± 0.001	1.79	0.081 ± 0.001	1.23
		Sour cherry	0.036 ± 0.001	2.78	0.037 ± 0.001	2.70	0.038 ± 0.001	2.63	0.047 ± 0.001	2.13	0.048 ± 0.001	2.08
	Delphinidin-3-*O*-sambubioside	Sour cherry	1.79 ± 0.02	1.12	2.40 ± 0.03	1.25	2.93 ± 0.03	1.02	3.47 ± 0.03	0.86	4.42 ± 0.05	1.13
		Raspberry	3.62 ± 0.05	1.38	3.81 ± 0.05	1.31	4.1 ± 0.1	2.44	4.9 ± 0.1	2.04	6.3 ± 0.1	1.59
	Cyanidin-3-*O*-sambubioside	Sour cherry	0.78 ± 0.01	1.28	1.06 ± 0.02	1.89	1.07 ± 0.01	0.93	1.36 ± 0.02	1.47	2.24 ± 0.01	0.45
		Raspberry	1.68 ± 0.04	2.38	1.69 ± 0.04	2.37	2.02 ± 0.01	0.49	2.39 ± 0.04	1.67	2.84 ± 0.04	1.41

Duration	Phenolic compound	Tea	60°C		70°C		80°C		90°C		100°C	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
10 min	Gallic acid	Black	0.45 ± 0.01	2.22	0.38 ± 0.01	2.63	0.56 ± 0.01	1.79	0.78 ± 0.01	1.28	0.94 ± 0.01	1.06
		Green	0.68 ± 0.01	1.47	1.35 ± 0.05	3.70	1.59 ± 0.04	2.52	1.75 ± 0.06	3.43	2.08 ± 0.07	3.37
		Sour cherry	0.402 ± 0.004	0.99	0.805 ± 0.004	0.49	0.812 ± 0.005	0.62	0.987 ± 0.002	0.20	1.275 ± 0.007	0.55
		Raspberry	1.57 ± 0.03	1.91	1.93 ± 0.03	1.55	2.02 ± 0.03	1.49	2.00 ± 0.03	1.50	2.17 ± 0.04	1.84
	Caffeic acid	Black	0.035 ± 0.001	2.86	0.038 ± 0.001	2.63	0.056 ± 0.001	1.79	0.068 ± 0.001	1.47	0.112 ± 0.003	2.68
		Green	0.025 ± 0.001	4.00	0.041 ± 0.001	2.44	n.d.	/	n.d.	/	0.072 ± 0.001	0.39
		Sour cherry	0.066 ± 0.001	1.51	0.094 ± 0.001	1.06	0.095 ± 0.001	1.05	0.108 ± 0.002	1.85	0.122 ± 0.002	1.64
		Raspberry	0.127 ± 0.002	1.57	0.152 ± 0.002	1.32	0.158 ± 0.003	1.90	0.268 ± 0.003	1.12	0.303 ± 0.003	0.99
	Protocatechuic acid	Green	0.54 ± 0.01	1.85	0.71 ± 0.01	1.41	n.d.	/	1.09 ± 0.02	1.83	1.35 ± 0.02	1.48
	Rutin	Black	0.55 ± 0.01	1.82	0.61 ± 0.01	1.64	0.69 ± 0.01	1.45	0.88 ± 0.01	1.14	1.07 ± 0.03	2.80
		Green	0.45 ± 0.01	2.22	0.89 ± 0.01	1.12	1.07 ± 0.02	1.87	1.38 ± 0.01	0.72	1.59 ± 0.01	0.63
		Raspberry	n.d.	/	0.205 ± 0.002	0.94	0.256 ± 0.002	0.78	0.257 ± 0.002	0.78	0.289 ± 0.002	0.69
	Morin	Black	0.25 ± 0.01	4.00	0.27 ± 0.01	3.70	0.26 ± 0.01	3.85	0.56 ± 0.01	1.79	0.74 ± 0.01	1.35
		Green	0.132 ± 0.003	2.27	0.76 ± 0.01	1.32	0.81 ± 0.01	1.23	0.89 ± 0.01	1.12	1.33 ± 0.03	2.25
	Quercetin	Black	0.102 ± 0.003	2.94	0.142 ± 0.003	2.11	0.182 ± 0.003	1.65	0.23 ± 0.01	4.35	0.26 ± 0.01	3.85
		Green	0.33 ± 0.01	3.03	0.38 ± 0.01	2.63	0.46 ± 0.01	2.17	0.65 ± 0.01	1.54	0.63 ± 0.01	1.59
	(+)-Catechin	Black	0.119 ± 0.001	0.84	0.139 ± 0.001	0.72	0.142 ± 0.003	2.11	0.162 ± 0.003	1.85	0.172 ± 0.003	1.74
		Green	0.146 ± 0.001	0.68	0.198 ± 0.001	0.51	0.232 ± 0.001	0.43	0.25 ± 0.01	4.00	0.228 ± 0.001	0.44
		Sour cherry	0.94 ± 0.01	1.06	1.45 ± 0.02	1.38	1.49 ± 0.02	1.34	n.d.	/	1.68 ± 0.03	1.79
		Raspberry	0.111 ± 0.002	1.80	0.172 ± 0.002	1.16	0.174 ± 0.002	1.15	0.223 ± 0.003	1.34	0.287 ± 0.003	1.04
	(-)-Epicatechin	Green	0.35 ± 0.01	2.86	0.48 ± 0.01	2.08	0.51 ± 0.01	1.96	0.53 ± 0.01	1.89	0.88 ± 0.01	1.14
		Sour cherry	0.24 ± 0.01	4.17	0.284 ± 0.005	1.76	0.324 ± 0.003	0.92	n.d.	/	0.338 ± 0.004	1.18
		Raspberry	0.168 ± 0.002	1.19	0.266 ± 0.002	0.75	0.312 ± 0.003	0.96	0.362 ± 0.003	0.83	0.567 ± 0.004	0.70
	(-)-Epigallocatechin	Sour cherry	0.054 ± 0.001	1.85	0.063 ± 0.001	1.59	0.093 ± 0.002	2.15	n.d.	/	0.115 ± 0.004	3.45
	Procyanidin B1	Black	0.125 ± 0.001	0.80	0.146 ± 0.001	0.68	0.148 ± 0.001	0.67	0.174 ± 0.001	0.57	0.185 ± 0.001	0.54
		Raspberry	0.108 ± 0.002	1.85	n.d.	/	0.134 ± 0.002	1.49	0.161 ± 0.002	1.24	0.159 ± 0.002	1.26
	Procyanidin B2	Green	0.094 ± 0.001	1.06	0.135 ± 0.001	0.74	n.d.	/	0.203 ± 0.003	1.48	0.33 ± 0.01	3.03
		Sour cherry	0.092 ± 0.003	3.26	0.132 ± 0.002	1.52	0.148 ± 0.003	2.03	0.175 ± 0.002	1.14	0.267 ± 0.003	1.12
	Procyanidin B3	Green	0.045 ± 0.001	2.22	0.054 ± 0.001	1.85	0.081 ± 0.001	1.23	0.087 ± 0.001	1.15	0.094 ± 0.001	1.06
		Sour cherry	0.039 ± 0.001	2.56	0.042 ± 0.001	2.38	n.d.	/	0.049 ± 0.001	2.04	0.059 ± 0.002	3.39
	Delphinidin-3-*O*-sambubioside	Sour cherry	2.17 ± 0.01	0.46	4.15 ± 0.04	0.96	4.88 ± 0.04	0.82	5.97 ± 0.05	0.84	8.92 ± 0.03	0.33
		Raspberry	3.31 ± 0.03	0.91	3.88 ± 0.03	0.77	5.22 ± 0.03	0.57	6.61 ± 0.02	0.30	8.11 ± 0.05	0.62
	Cyanidin-3-*O*-sambubioside	Sour cherry	0.98 ± 0.02	2.04	1.24 ± 0.02	1.61	1.54 ± 0.02	1.30	1.93 ± 0.01	0.52	2.38 ± 0.02	0.84
		Raspberry	3.03 ± 0.04	1.32	n.d.	/	3.52 ± 0.03	0.85	3.66 ± 0.03	0.82	4.01 ± 0.04	0.99

Duration	Phenolic compound	Tea	60°C		70°C		80°C		90°C		100°C	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
15 min	Gallic acid	Black	0.43 ± 0.01	2.33	0.56 ± 0.01	1.79	0.62 ± 0.01	1.61	0.76 ± 0.01	1.32	1.04 ± 0.04	3.85
		Green	0.93 ± 0.03	3.22	1.51 ± 0.04	2.65	1.68 ± 0.05	2.98	2.15 ± 0.05	2.32	2.39 ± 0.06	2.51
		Sour cherry	0.615 ± 0.003	0.49	0.914 ± 0.004	0.44	0.982 ± 0.004	0.41	n.d.	/	1.015 ± 0.005	0.49
		Raspberry	1.39 ± 0.03	2.16	1.94 ± 0.03	1.55	1.95 ± 0.03	1.54	2.23 ± 0.03	1.35	2.31 ± 0.03	1.30
	Caffeic acid	Black	0.034 ± 0.001	2.94	0.039 ± 0.001	2.56	0.058 ± 0.001	1.72	0.064 ± 0.001	1.56	0.111 ± 0.003	2.70
		Green	0.033 ± 0.001	3.03	n.d.	/	0.068 ± 0.001	1.47	0.111 ± 0.001	0.90	0.121 ± 0.001	0.83
		Sour cherry	0.064 ± 0.001	1.56	0.099 ± 0.001	1.01	0.105 ± 0.002	1.90	0.128 ± 0.002	1.56	0.132 ± 0.002	1.51
		Raspberry	0.164 ± 0.003	1.83	0.163 ± 0.003	1.84	0.176 ± 0.003	1.70	0.279 ± 0.003	1.07	0.324 ± 0.002	0.62
	Protocatechuic acid	Green	0.66 ± 0.02	3.03	0.74 ± 0.02	2.70	n.d.	/	1.15 ± 0.03	2.61	1.25 ± 0.03	2.40
	Rutin	Black	0.46 ± 0.01	2.17	0.75 ± 0.01	1.33	0.75 ± 0.01	1.33	1.07 ± 0.03	2.80	1.16 ± 0.01	0.86
		Green	0.55 ± 0.01	1.82	0.64 ± 0.01	1.56	0.99 ± 0.01	1.01	1.58 ± 0.01	0.63	1.22 ± 0.01	0.82
		Raspberry	0.147 ± 0.002	1.36	n.d.	/	0.259 ± 0.002	0.77	0.281 ± 0.002	0.71	0.287 ± 0.002	0.70
	Morin	Black	0.31 ± 0.01	3.22	0.39 ± 0.01	2.56	0.58 ± 0.01	1.72	0.64 ± 0.01	1.56	1.03 ± 0.02	1.94
		Green	0.48 ± 0.01	2.08	0.94 ± 0.01	1.06	0.95 ± 0.01	1.05	n.d.	/	1.12 ± 0.03	2.68
	Quercetin	Black	0.164 ± 0.001	0.61	0.21 ± 0.01	4.76	0.22 ± 0.01	4.54	0.24 ± 0.01	4.17	0.322 ± 0.003	0.93
		Green	0.43 ± 0.01	2.32	0.42 ± 0.01	2.38	0.55 ± 0.01	1.82	0.58 ± 0.01	1.72	0.65 ± 0.01	1.54
	(+)-Catechin	Black	0.122 ± 0.003	2.46	0.133 ± 0.004	3.01	0.151 ± 0.002	1.32	0.171 ± 0.002	1.17	0.21 ± 0.01	4.76
		Green	0.178 ± 0.001	0.56	0.205 ± 0.001	0.49	0.219 ± 0.001	0.46	0.255 ± 0.001	0.39	0.264 ± 0.001	0.38
		Sour cherry	1.09 ± 0.02	1.83	1.52 ± 0.02	1.32	1.57 ± 0.03	1.91	n.d.	/	1.89 ± 0.03	1.59
		Raspberry	0.113 ± 0.002	1.77	0.145 ± 0.002	1.38	0.188 ± 0.002	1.06	n.d.	/	0.302 ± 0.003	0.99
	(-)-Epicatechin	Green	0.41 ± 0.01	2.44	0.46 ± 0.01	2.17	0.48 ± 0.01	2.08	0.66 ± 0.01	1.51	0.78 ± 0.01	1.28
		Sour cherry	0.253 ± 0.003	1.19	0.299 ± 0.004	1.33	n.d.	/	0.304 ± 0.004	1.32	0.350 ± 0.003	0.8
		Raspberry	0.191 ± 0.002	1.05	0.309 ± 0.002	0.65	0.381 ± 0.003	0.79	n.d.	/	0.881 ± 0.004	0.45
	(-)-Epigallocatechin	Sour cherry	0.068 ± 0.001	1.47	0.072 ± 0.001	1.39	0.108 ± 0.001	0.92	0.104 ± 0.003	2.88	0.115 ± 0.002	1.74
	Procyanidin B1	Black	0.149 ± 0.001	0.67	0.151 ± 0.001	0.66	0.172 ± 0.001	0.58	0.184 ± 0.001	0.54	0.197 ± 0.001	0.51
		Raspberry	0.113 ± 0.001	0.88	0.118 ± 0.001	0.85	0.148 ± 0.003	2.03	n.d.	/	0.162 ± 0.002	1.23
	Procyanidin B2	Green	0.075 ± 0.002	2.67	0.182 ± 0.001	0.55	n.d.	/	0.228 ± 0.001	0.44	0.31 ± 0.01	3.22
		Sour cherry	0.097 ± 0.002	2.06	0.139 ± 0.003	2.16	n.d.	/	0.181 ± 0.002	1.10	0.261 ± 0.002	0.77
	Procyanidin B3	Green	0.058 ± 0.001	1.72	0.069 ± 0.001	1.45	0.074 ± 0.001	1.35	0.094 ± 0.001	1.06	0.092 ± 0.001	1.09
		Sour cherry	0.037 ± 0.001	2.70	0.043 ± 0.001	2.33	0.051 ± 0.001	1.96	0.056 ± 0.001	1.79	n.d.	/
	Delphinidin-3-*O*-sambubioside	Sour cherry	3.73 ± 0.02	0.54	4.84 ± 0.01	0.21	5.04 ± 0.02	0.39	6.23 ± 0.02	0.32	10.4 ± 0.1	0.96
		Raspberry	5.42 ± 0.04	0.74	5.63 ± 0.02	3.55	6.14 ± 0.05	0.81	6.78 ± 0.05	0.74	8.15 ± 0.05	0.61
	Cyanidin-3-*O*-sambubioside	Sour cherry	n.d.	/	1.54 ± 0.02	1.30	1.53 ± 0.02	1.31	2.13 ± 0.01	0.47	2.58 ± 0.02	0.77
		Raspberry	2.51 ± 0.03	1.19	3.27 ± 0.04	1.22	n.d.	/	4.02 ± 0.04	0.99	4.38 ± 0.04	0.91

Duration	Phenolic compound	Tea	60°C		70°C		80°C		90°C		100°C	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
20 min	Gallic acid	Black	0.51 ± 0.01	1.96	0.82 ± 0.01	1.22	0.75 ± 0.01	1.33	0.90 ± 0.01	1.11	1.62 ± 0.04	2.47
		Green	0.71 ± 0.01	1.41	1.22 ± 0.04	3.28	2.67 ± 0.06	2.25	2.37 ± 0.06	2.53	3.25 ± 0.06	1.85
		Sour cherry	0.628 ± 0.004	0.64	0.927 ± 0.004	0.43	0.985 ± 0.004	0.41	0.982 ± 0.004	0.41	1.054 ± 0.003	0.28
		Raspberry	1.84 ± 0.03	1.63	1.97 ± 0.03	1.52	2.18 ± 0.04	1.83	2.22 ± 0.03	1.35	2.66 ± 0.03	1.13
	Caffeic acid	Black	0.034 ± 0.001	2.94	0.053 ± 0.001	1.86	0.069 ± 0.001	1.45	0.074 ± 0.001	1.35	0.115 ± 0.003	2.61
		Green	n.d.	/	0.065 ± 0.001	1.54	0.082 ± 0.001	1.22	0.118 ± 0.001	0.85	n.d.	/
		Sour cherry	0.067 ± 0.002	2.99	0.105 ± 0.003	2.86	n.d.	/	0.138 ± 0.003	2.17	0.132 ± 0.004	3.03
		Raspberry	n.d.	/	0.232 ± 0.003	1.29	0.233 ± 0.003	1.29	0.243 ± 0.003	1.23	0.337 ± 0.003	0.89
	Protocatechuic acid	Green	0.68 ± 0.01	1.47	n.d.	/	0.94 ± 0.01	1.06	1.07 ± 0.02	1.87	1.34 ± 0.03	2.24
	Rutin	Black	0.59 ± 0.01	1.69	0.98 ± 0.01	1.02	1.34 ± 0.01	0.74	1.51 ± 0.01	0.66	1.57 ± 0.03	1.91
		Green	0.62 ± 0.01	1.61	0.73 ± 0.01	1.37	0.84 ± 0.01	1.19	1.34 ± 0.01	0.74	1.58 ± 0.01	0.63
		Raspberry	0.152 ± 0.002	1.31	n.d.	/	0.268 ± 0.002	0.75	0.302 ± 0.002	0.66	0.368 ± 0.002	0.54
	Morin	Black	0.26 ± 0.01	3.84	0.29 ± 0.01	3.45	0.68 ± 0.01	1.47	0.86 ± 0.01	1.16	1.06 ± 0.04	3.77
		Green	0.65 ± 0.01	1.54	1.11 ± 0.04	3.60	1.30 ± 0.04	3.08	1.31 ± 0.04	3.05	1.32 ± 0.03	2.27
	Quercetin	Black	0.182 ± 0.003	1.65	0.205 ± 0.001	0.49	0.322 ± 0.003	0.93	0.33 ± 0.01	3.03	0.38 ± 0.01	2.63
		Green	0.67 ± 0.01	1.49	0.58 ± 0.01	1.72	0.74 ± 0.01	1.35	0.78 ± 0.01	1.28	0.79 ± 0.01	1.26
	(+)-Catechin	Black	0.141 ± 0.001	0.71	0.135 ± 0.004	2.96	0.171 ± 0.001	0.58	0.182 ± 0.003	1.65	0.212 ± 0.003	1.41
		Green	0.258 ± 0.001	0.39	0.262 ± 0.001	0.38	0.281 ± 0.001	0.36	0.285 ± 0.001	0.35	0.365 ± 0.003	0.82
		Sour cherry	1.50 ± 0.01	0.67	1.54 ± 0.04	2.59	1.82 ± 0.04	2.19	n.d.	/	2.42 ± 0.04	1.65
		Raspberry	0.116 ± 0.002	1.72	n.d.	/	0.194 ± 0.001	0.51	0.244 ± 0.002	0.82	0.354 ± 0.003	0.85
	(-)-Epicatechin	Green	0.57 ± 0.01	1.75	0.65 ± 0.01	1.54	0.68 ± 0.01	1.47	0.76 ± 0.01	1.32	n.d.	/
		Sour cherry	0.309 ± 0.003	0.97	0.329 ± 0.004	1.22	0.356 ± 0.004	1.12	n.d.	/	0.474 ± 0.004	0.84
		Raspberry	0.233 ± 0.003	1.29	0.356 ± 0.003	0.84	0.337 ± 0.002	0.59	0.659 ± 0.004	0.61	n.d.	/
	(-)-Epigallocatechin	Sour cherry	0.099 ± 0.003	3.03	0.119 ± 0.001	0.84	0.125 ± 0.004	3.20	n.d.	/	0.143 ± 0.003	2.09
	Procyanidin B1	Black	0.146 ± 0.001	0.68	0.158 ± 0.001	0.63	0.184 ± 0.001	0.54	0.186 ± 0.001	0.54	0.198 ± 0.001	0.50
		Raspberry	0.120 ± 0.002	1.67	0.122 ± 0.002	1.64	n.d.	/	0.175 ± 0.002	0.14	0.184 ± 0.002	1.09
	Procyanidin B2	Green	0.165 ± 0.002	1.21	0.251 ± 0.001	0.40	0.235 ± 0.002	0.85	0.43 ± 0.01	2.32	0.66 ± 0.01	1.51
		Sour cherry	0.105 ± 0.002	1.90	0.141 ± 0.003	2.13	0.160 ± 0.003	1.88	0.187 ± 0.003	1.60	0.279 ± 0.002	0.72
	Procyanidin B3	Green	0.102 ± 0.001	0.98	0.103 ± 0.001	0.97	0.105 ± 0.001	0.95	0.135 ± 0.001	0.74	n.d.	/
		Sour cherry	0.046 ± 0.001	2.17	0.063 ± 0.001	1.59	n.d.	/	0.068 ± 0.002	2.94	0.083 ± 0.002	2.41
	Delphinidin-3-*O*-sambubioside	Sour cherry	4.49 ± 0.01	0.22	5.86 ± 0.03	0.51	6.21 ± 0.02	0.32	8.38 ± 0.02	0.24	17.5 ± 0.3	1.71
		Raspberry	6.58 ± 0.02	0.30	7.62 ± 0.03	0.39	8.42 ± 0.04	0.47	14.4 ± 0.1	0.69	16.9 ± 0.1	0.59
	Cyanidin-3-*O*-sambubioside	Sour cherry	1.42 ± 0.02	1.41	n.d.	/	2.32 ± 0.01	0.43	2.67 ± 0.02	0.75	2.97 ± 0.03	1.01
		Raspberry	2.89 ± 0.03	1.04	n.d.	/	3.53 ± 0.03	0.85	3.89 ± 0.03	0.77	5.29 ± 0.04	0.76

n.d.: not detected.

(-)-Epicatechin content increased with the increase in temperature, except for 5 min at 100°C, and 20 min at 100°C. Procyanidin B2 content increased with the increase in temperature, except in several cases (10 min at 80°C, 15 min at 80°C, and 10 min at 80°C). Procyanidin B3 content increased with the increase in temperature, except in the following cases: 15 min at 100 and 20°C.

The investigation on the effect of steeping temperature and duration on various tea infusions obtained from teas packed in bags, among them, black and green teas, showed somewhat different results (Yang *et al.*, 2007). A higher number of exceptions from the increasing trend of particular phenolic compounds with the increase in temperature in the case of raspberry and cherry teas could have been attributed to the very complex matrix in both cases, thus affecting the processes occurring within their aqueous system.

Effect of storage time and temperature on total flavonoid content

Many flavonoid compounds (*e.g.*, procyanidins and catechins) are heat-sensitive, and can undergo chemical degradation during heat processing or even storage (Ananingsih *et al.*, 2013). Therefore, it was important to investigate the total flavonoid content depending on the storage temperature and time. Previously, we investigated the effect of storage temperature and thermal processing on catechins, procyanidins, and total flavonoid stability in commercially available cocoa powders (Mrmošanin *et al.*, 2015).

The effect of storage provides valuable data on keeping different types of tea under different storage conditions (Table 3). When tea bags of black tea were kept at 4, 25, and 35°C, the maximal value of total flavonoids was observed on the 40th day (37.27, 49.34, and 44.64 mgCE/g, respectively). A somehow different trend was obtained in the case of green tea under different storage temperatures (4, 25, and 35°C); maximal values on the 40th day of storage were observed at 4 and 25°C (48.84 and 55.39 mgCE/g, respectively), and at 35°C on the 50th days of storage (58.76 mgCE/g). Irregular behaviour was observed for black and green teas, and fruit teas (sour cherry and raspberry).

Storage conditions effects were investigated before on the content of total flavonoids in chocolate. Similar to our study, it was found that they degraded faster at elevated temperatures than at lower temperatures (Pavlovic *et al.*, 2017). This is in accordance with some earlier studies on strawberry and pineapple juices (Odriozola-Serrano *et al.*, 2009; Zheng and Lu, 2011). However, it was proposed that the extraction method is also important besides storage for the bioavailability and stability of flavonoids (Liu *et al.*, 2022). Storage conditions were also investigated on the quantity of tea catechins. It was observed that the lower storage temperature extended the catechins half-life (Demeule *et al.*, 2002), and that a significant amount of catechins was degraded after six months of storage (Friedman *et al.*, 2009). The aromatic and sensory quality of Huangshan Maofeng tea was preserved when it was stored at lower temperatures (Dai *et al.*, 2019).

Computationally, the best results, based on the obtained model for full factorial design ($p = 0.0032$) for black tea were 33.2 days at 4°C (Figure 1B), for green tea ($p = 0.0002$), 23.2 days at 19.6°C (Figure 1B), and for raspberry ($p = 0.0023$), 33.7 days at 13.4°C (Figure 1B).

Effect of storage time and temperature on selected phenolic compounds contents

Seven compounds were monitored in black tea during different numbers of storage days and temperatures: gallic acid, caffeic acid, rutin, morin, quercetin, (+)-catechin, and procyanidin B1 (Table 4). At 4°C for 50-day period, the contents of gallic acid, caffeic acid, rutin, morin, and (+)-catechin did not show a regular trend. The contents of quercetin and procyanidin B1 at 4°C showed an increasing trend during the 50-day storage period. Quite good regularity was observed for all quantified compounds at 25°C for 50-day storage period with few exceptions: caffeic acid at the 30th day of storage, quercetin at the 40th day of storage, and procyanidin B1 at the 30th day of storage. An irregular trend for the quantified phenolic compounds was also observed at 35°C, except for (+)-catechin content, which showed a regular increasing trend.

Eight compounds were quantified and monitored during the 50-day storage period at 4°C in the fridge for the raspberry tea (Table 4): gallic acid, caffeic acid, (+)-catechin, (-)-epicatechin, procyanidin B1, rutin, delphinidin-3-*O*-sambubioside, and cyanidin-3-*O*-sambubioside. An increasing trend was noticed in all cases, with one exception per compound, except gallic acid and

Table 3. Total flavonoid contents (mgCE/g) in black, green, sour cherry, and raspberry teas based on storage temperature and duration.

Temperature	Tea	10th day		20th day		30th day		40th day		50th day	
		c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
4°C	Black	24.91 ± 0.78	3.13	29.43 ± 0.70	2.38	36.89 ± 0.00	0.00	37.27 ± 0.00	0.00	36.24 ± 0.00	0.00
	Green	37.39 ± 0.92	2.46	42.29 ± 0.90	2.13	46.98 ± 0.93	1.98	48.84 ± 0.47	0.96	42.58 ± 0.47	1.10
	Sour cherry	22.26 ± 0.36	1.62	23.06 ± 0.36	1.56	27.47 ± 0	0.00	29.21 ± 0.36	1.23	30.70 ± 0.37	1.20
	Raspberry	31.07 ± 0.92	2.96	35.44 ± 0.94	2.65	39.68 ± 0.47	1.18	40.76 ± 0.00	0.00	38.25 ± 0.47	1.23
25°C	Black	33.07 ± 0.74	2.24	41.10 ± 0.75	1.82	43.81 ± 1.51	3.44	49.34 ± 0	0.00	45.27 ± 0.79	1.74
	Green	43.37 ± 0.47	1.08	49.64 ± 0.48	0.97	53.16 ± 0.47	0.88	55.39 ± 0.48	0.87	53.73 ± 0.48	0.89
	Sour cherry	57.6 ± 0.73	1.26	61.15 ± 0.00	0.00	33.66 ± 0.71	2.11	35.41 ± 0.35	0.99	35.23 ± 0.00	0.00
	Raspberry	37.87 ± 0.95	2.51	42.80 ± 0.94	2.20	44.59 ± 0.49	1.10	43.34 ± 0.47	1.08	48.01 ± 0.00	0.00
35°C	Black	29.34 ± 0.75	2.56	37.29 ± 0.78	2.09	42.30 ± 1.65	3.90	44.64 ± 0.00	0.00	42.59 ± 0.00	0.00
	Green	47.82 ± 0.57	1.19	52.13 ± 0.53	1.02	57.02 ± 0.54	0.95	54.32 ± 0.51	0.94	58.76 ± 1.11	1.89
	Sour cherry	28.86 ± 0.75	2.59	32.22 ± 0.40	1.24	35.77 ± 0.40	1.12	34.27 ± 0.00	0.00	33.27 ± 0.39	1.17
	Raspberry	37.42 ± 0.50	1.33	41.34 ± 0.48	1.16	40.97 ± 0.71	1.73	43.31 ± 0.48	1.11	44.52 ± 0.48	1.08

Table 4. Total phenolic contents (mg/g) in black, green, sour cherry, and raspberry teas based on storage temperature and duration.

Temperature	Phenolic compound	Tea	10th day		20th day		30th day		40th day		50th day	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
4°C	Gallic acid	Black	0.33 ± 0.01	3.03	0.52 ± 0.01	1.92	0.51 ± 0.01	1.96	0.85 ± 0.01	1.18	0.73 ± 0.01	1.37
		Green	1.09 ± 0.04	3.67	1.17 ± 0.05	4.27	1.41 ± 0.05	3.55	1.48 ± 0.06	4.05	2.02 ± 0.04	1.98
		Sour cherry	0.521 ± 0.003	0.58	0.614 ± 0.005	0.81	0.847 ± 0.005	0.59	0.839 ± 0.002	0.24	1.27 ± 0.01	0.79
		Raspberry	1.14 ± 0.02	1.75	1.57 ± 0.03	1.91	1.73 ± 0.03	1.73	2.05 ± 0.04	1.95	2.24 ± 0.04	1.79
	Caffeic acid	Black	0.033 ± 0.001	3.03	0.032 ± 0.001	3.12	0.032 ± 0.001	3.12	0.055 ± 0.001	1.82	0.055 ± 0.001	1.82
		Green	n.d.	/	0.025 ± 0.001	4.00	0.035 ± 0.001	2.86	0.081 ± 0.001	1.23	n.d.	/
		Sour cherry	0.052 ± 0.002	3.85	0.089 ± 0.002	2.25	0.082 ± 0.002	2.44	0.094 ± 0.002	2.13	0.102 ± 0.002	1.96
		Raspberry	0.139 ± 0.002	1.44	0.147 ± 0.002	1.36	0.184 ± 0.002	1.09	0.203 ± 0.002	0.98	n.d.	/
	Protocatechuic acid	Green	n.d.	/	0.42 ± 0.01	2.38	0.64 ± 0.01	1.56	0.89 ± 0.01	1.12	n.d.	/
	Rutin	Black	0.39 ± 0.01	2.56	0.74 ± 0.01	1.35	0.77 ± 0.01	1.30	1.23 ± 0.02	1.63	1.17 ± 0.02	1.71
		Green	0.193 ± 0.001	0.52	n.d.	/	n.d.	/	0.212 ± 0.003	1.42	n.d.	/
		Raspberry	0.125 ± 0.001	0.80	0.231 ± 0.002	0.86	0.237 ± 0.003	1.26	n.d.	/	0.242 ± 0.003	1.24
	Morin	Black	0.32 ± 0.01	3.12	0.202 ± 0.003	1.49	0.34 ± 0.01	2.94	0.61 ± 0.01	1.64	0.51 ± 0.01	1.96
		Green	0.154 ± 0.006	3.90	0.49 ± 0.01	2.04	0.65 ± 0.01	1.54	0.87 ± 0.01	1.15	1.08 ± 0.02	1.85
	Quercetin	Black	0.112 ± 0.003	2.68	0.133 ± 0.003	2.25	0.192 ± 0.003	1.56	0.26 ± 0.01	3.85	0.28 ± 0.01	3.57
		Green	0.24 ± 0.01	4.17	0.31 ± 0.01	3.22	0.28 ± 0.01	3.57	n.d.	/	0.39 ± 0.01	2.56
	(+)-Catechin	Black	0.122 ± 0.003	2.46	0.144 ± 0.001	0.69	0.169 ± 0.001	0.59	0.214 ± 0.001	0.47	0.194 ± 0.002	1.03
		Green	0.106 ± 0.002	1.89	0.110 ± 0.001	0.91	0.215 ± 0.001	0.46	0.251 ± 0.001	0.40	0.247 ± 0.001	0.40
		Sour cherry	0.86 ± 0.02	2.33	1.35 ± 0.02	1.48	1.54 ± 0.02	1.29	1.57 ± 0.04	2.55	1.92 ± 0.03	1.56
		Raspberry	0.082 ± 0.001	1.22	0.121 ± 0.002	1.65	0.122 ± 0.002	1.64	0.133 ± 0.001	0.75	n.d.	/
	(-)-Epicatechin	Green	0.085 ± 0.001	1.18	0.145 ± 0.001	0.69	0.31 ± 0.01	3.22	0.32 ± 0.01	3.12	0.42 ± 0.01	2.38
		Sour cherry	0.177 ± 0.001	0.56	0.271 ± 0.003	1.11	0.261 ± 0.003	1.15	0.269 ± 0.003	1.12	0.377 ± 0.003	0.79
		Raspberry	0.225 ± 0.003	1.33	0.252 ± 0.003	1.19	0.263 ± 0.002	0.76	n.d.	/	0.315 ± 0.004	1.27
	(-)-Epigallocatechin	Sour cherry	0.061 ± 0.001	1.64	0.085 ± 0.003	3.52	0.093 ± 0.003	3.23	0.124 ± 0.003	2.42	0.119 ± 0.002	1.68
	Procyanidin B1	Black	0.112 ± 0.001	0.89	0.164 ± 0.001	0.61	0.167 ± 0.001	0.60	0.254 ± 0.001	0.39	0.341 ± 0.001	0.29
		Raspberry	0.109 ± 0.001	0.92	0.111 ± 0.002	1.80	n.d.	/	0.142 ± 0.002	1.41	0.185 ± 0.002	1.08
	Procyanidin B2	Green	n.d.	/	0.085 ± 0.001	1.18	0.176 ± 0.001	0.57	0.188 ± 0.001	0.53	0.186 ± 0.001	0.54
		Sour cherry	0.098 ± 0.001	1.02	0.157 ± 0.002	1.27	0.158 ± 0.001	0.63	0.171 ± 0.003	1.75	n.d.	/
	Procyanidin B3	Green	n.d.	/	0.034 ± 0.001	2.94	0.063 ± 0.001	1.59	0.093 ± 0.001	1.07	0.088 ± 0.001	1.14
		Sour cherry	0.023 ± 0.001	4.35	0.026 ± 0.001	3.84	0.050 ± 0.001	2.00	0.082 ± 0.001	1.22	n.d.	/
	Delphinidin-3-*O*-sambubioside	Sour cherry	1.446 ± 0.004	0.89	1.52 ± 0.01	0.66	4.25 ± 0.02	0.47	5.87 ± 0.02	0.34	8.92 ± 0.03	0.33
		Raspberry	2.93 ± 0.02	0.68	4.42 ± 0.04	0.90	6.3 ± 0.1	1.59	6.61 ± 0.02	0.30	9.6 ± 0.1	1.04
	Cyanidin-3-*O*-sambubioside	Sour cherry	0.712 ± 0.002	0.28	0.824 ± 0.002	0.24	1.22 ± 0.02	1.64	1.68 ± 0.01	0.59	n.d.	/
		Raspberry	1.22 ± 0.03	2.46	2.13 ± 0.04	1.88	2.15 ± 0.03	1.40	2.87 ± 0.03	1.04	n.d.	/

Temperature	Phenolic compound	Tea	10th day		20th day		30th day		40th day		50th day	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
25°C	Gallic acid	Black	0.67 ± 0.01	1.49	0.86 ± 0.01	1.16	0.95 ± 0.01	1.05	1.45 ± 0.05	3.45	2.09 ± 0.06	2.87
		Green	1.59 ± 0.04	2.52	1.35 ± 0.04	2.96	1.82 ± 0.04	2.20	2.27 ± 0.07	3.08	2.31 ± 0.06	2.60
		Sour cherry	0.788 ± 0.005	0.63	0.878 ± 0.004	4.56	0.942 ± 0.003	0.32	1.10 ± 0.01	0.91	1.58 ± 0.03	1.89
		Raspberry	1.52 ± 0.03	1.97	1.83 ± 0.03	1.64	1.93 ± 0.03	1.55	2.15 ± 0.04	1.86	2.24 ± 0.03	1.34
	Caffeic acid	Black	0.037 ± 0.001	2.70	0.044 ± 0.001	2.27	n.d.	/	0.069 ± 0.001	1.45	0.094 ± 0.001	1.06
		Green	0.031 ± 0.001	3.22	0.041 ± 0.001	2.44	n.d.	/	0.31 ± 0.01	3.22	0.45 ± 0.01	2.22
		Sour cherry	0.077 ± 0.001	1.29	0.102 ± 0.002	1.96	0.105 ± 0.002	1.90	0.122 ± 0.002	1.64	0.149 ± 0.001	0.67
		Raspberry	0.182 ± 0.002	1.10	0.195 ± 0.003	1.54	0.211 ± 0.003	1.42	0.301 ± 0.003	1.00	0.303 ± 0.003	0.99
	Protocatechuic acid	Green	0.51 ± 0.01	1.96	n.d.	/	0.69 ± 0.01	1.45	0.89 ± 0.01	1.12	1.11 ± 0.03	2.70
	Rutin	Black	0.77 ± 0.02	2.60	1.05 ± 0.01	0.95	1.38 ± 0.02	1.45	1.89 ± 0.01	0.53	2.08 ± 0.04	1.92
		Green	0.25 ± 0.01	4.00	0.26 ± 0.01	3.85	0.33 ± 0.01	3.03	0.51 ± 0.01	1.96	0.632 ± 0.003	0.47
		Raspberry	0.215 ± 0.002	0.93	0.251 ± 0.002	0.80	0.268 ± 0.002	0.74	0.306 ± 0.002	0.65	0.328 ± 0.003	0.91
	Morin	Black	0.41 ± 0.01	2.44	0.66 ± 0.01	1.52	0.72 ± 0.01	1.39	0.85 ± 0.01	1.17	0.88 ± 0.01	1.14
		Green	0.57 ± 0.01	1.75	0.58 ± 0.01	1.72	0.81 ± 0.01	1.23	1.09 ± 0.03	2.75	1.54 ± 0.02	1.30
	Quercetin	Black	0.142 ± 0.003	2.11	0.162 ± 0.003	1.85	0.33 ± 0.01	3.03	0.31 ± 0.01	3.22	0.64 ± 0.01	1.56
		Green	0.33 ± 0.01	3.03	0.28 ± 0.01	3.57	0.46 ± 0.01	2.17	0.56 ± 0.01	1.79	0.57 ± 0.01	1.75
	(+)-Catechin	Black	0.143 ± 0.004	2.80	0.149 ± 0.001	0.67	0.202 ± 0.003	1.49	0.212 ± 0.003	1.41	0.441 ± 0.003	0.68
		Green	0.115 ± 0.001	0.87	0.228 ± 0.001	0.44	0.232 ± 0.001	0.43	0.261 ± 0.001	0.38	0.332 ± 0.001	0.30
		Sour cherry	1.32 ± 0.02	1.52	1.63 ± 0.03	1.84	1.88 ± 0.03	1.60	2.11 ± 0.02	0.95	2.33 ± 0.02	0.86
		Raspberry	0.093 ± 0.001	1.07	0.128 ± 0.002	1.56	0.146 ± 0.002	1.37	0.141 ± 0.001	0.71	0.176 ± 0.001	0.57
	(-)-Epicatechin	Green	0.48 ± 0.01	2.08	0.61 ± 0.01	1.64	0.56 ± 0.01	1.79	0.59 ± 0.01	1.69	0.67 ± 0.01	1.49
		Sour cherry	0.264 ± 0.002	0.76	0.338 ± 0.004	1.18	0.343 ± 0.004	1.17	n.d.	/	0.422 ± 0.002	0.47
		Raspberry	0.266 ± 0.002	0.75	n.d.	/	0.329 ± 0.002	0.61	0.456 ± 0.002	0.44	0.523 ± 0.002	0.38
	(-)-Epigallocatechin	Sour cherry	0.108 ± 0.002	1.85	0.115 ± 0.004	3.45	0.116 ± 0.002	1.72	0.162 ± 0.002	1.23	0.171 ± 0.002	1.17
	Procyanidin B1	Black	0.146 ± 0.001	0.68	0.217 ± 0.001	0.46	n.d.	/	0.285 ± 0.001	0.35	0.428 ± 0.001	0.23
		Raspberry	0.131 ± 0.001	0.76	0.118 ± 0.001	0.85	0.149 ± 0.003	2.01	0.171 ± 0.002	1.17	0.365 ± 0.002	0.55
	Procyanidin B2	Green	0.143 ± 0.001	0.69	0.147 ± 0.001	0.68	0.171 ± 0.001	0.58	0.151 ± 0.001	0.66	0.203 ± 0.003	1.48
		Sour cherry	0.128 ± 0.002	1.56	0.147 ± 0.002	1.36	0.188 ± 0.002	1.06	n.d.	/	0.267 ± 0.003	1.12
	Procyanidin B3	Green	0.054 ± 0.001	1.85	0.076 ± 0.001	1.32	0.087 ± 0.001	1.15	0.108 ± 0.001	0.93	0.109 ± 0.001	0.92
		Sour cherry	0.059 ± 0.002	3.39	0.064 ± 0.001	1.56	0.131 ± 0.002	1.53	0.129 ± 0.001	0.77	0.254 ± 0.002	0.79
	Delphinidin-3-*O*-sambubioside	Sour cherry	3.32 ± 0.03	0.90	4.25 ± 0.01	0.23	6.88 ± 0.02	0.29	9.24 ± 0.02	0.21	12.47 ± 0.03	0.24
		Raspberry	4.51 ± 0.05	1.11	5.75 ± 0.04	0.69	8.3 ± 0.1	1.20	8.41 ± 0.05	0.59	n.d.	/
	Cyanidin-3-*O*-sambubioside	Sour cherry	1.47 ± 0.01	0.68	1.58 ± 0.01	0.63	1.99 ± 0.01	0.50	2.02 ± 0.01	0.49	2.38 ± 0.02	0.84
		Raspberry	2.05 ± 0.03	1.46	2.86 ± 0.04	1.40	3.03 ± 0.04	1.32	3.54 ± 0.04	1.13	4.54 ± 0.05	1.10

Temperature	Phenolic compound	Tea	10th day		20th day		30th day		40th day		50th day	
			c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD	c_{av} ± SD	RSD
35°C	Gallic acid	Black	0.46 ± 0.01	2.17	0.67 ± 0.01	1.49	0.67 ± 0.01	1.49	0.88 ± 0.01	1.14	1.74 ± 0.06	3.45
		Green	1.92 ± 0.05	2.60	2.06 ± 0.07	3.40	2.01 ± 0.04	1.99	2.19 ± 0.08	3.65	2.28 ± 0.05	2.19
		Sour cherry	0.614 ± 0.005	0.81	0.864 ± 0.004	0.46	0.883 ± 0.004	0.45	0.906 ± 0.004	0.44	1.34 ± 0.02	1.49
		Raspberry	1.22 ± 0.04	3.28	1.77 ± 0.02	1.13	1.89 ± 0.03	1.59	2.09 ± 0.04	1.91	2.19 ± 0.04	1.83
	Caffeic acid	Black	0.032 ± 0.001	3.12	0.035 ± 0.001	2.86	0.048 ± 0.001	2.08	0.062 ± 0.001	1.61	0.058 ± 0.001	1.72
		Green	0.035 ± 0.001	2.86	0.042 ± 0.001	2.38	0.111 ± 0.001	0.90	n.d.	/	0.122 ± 0.003	2.46
		Sour cherry	0.085 ± 0.002	2.35	0.088 ± 0.002	2.27	0.101 ± 0.003	2.97	0.105 ± 0.002	1.90	0.134 ± 0.003	2.24
		Raspberry	0.173 ± 0.003	1.73	0.183 ± 0.003	1.64	n.d.	/	0.217 ± 0.003	1.38	0.227 ± 0.003	1.32
	Protocatechuic acid	Green	0.34 ± 0.01	2.94	0.56 ± 0.01	1.79	n.d.	/	0.71 ± 0.01	1.41	n.d.	/
	Rutin	Black	0.59 ± 0.01	1.69	0.96 ± 0.01	1.04	n.d.	/	1.51 ± 0.03	1.99	1.24 ± 0.01	0.81
		Green	n.d.	/	0.322 ± 0.003	0.93	n.d.	/	0.45 ± 0.01	2.22	0.57 ± 0.01	1.75
		Raspberry	0.214 ± 0.001	0.47	0.241 ± 0.002	0.83	0.259 ± 0.002	0.77	0.289 ± 0.002	0.69	n.d.	/
	Morin	Black	0.35 ± 0.01	2.86	0.43 ± 0.01	2.32	0.48 ± 0.01	2.08	0.51 ± 0.01	1.96	n.d.	/
		Green	0.202 ± 0.003	1.48	0.43 ± 0.01	2.33	n.d.	/	0.99 ± 0.01	1.01	1.27 ± 0.04	3.15
	Quercetin	Black	0.124 ± 0.001	0.81	0.152 ± 0.003	1.97	0.28 ± 0.01	3.57	0.29 ± 0.01	3.45	n.d.	/
		Green	0.31 ± 0.01	3.22	0.29 ± 0.01	3.45	0.35 ± 0.01	2.86	0.51 ± 0.01	1.96	0.48 ± 0.01	2.08
	(+)-Catechin	Black	0.128 ± 0.002	1.56	0.151 ± 0.002	1.32	0.181 ± 0.001	0.55	0.192 ± 0.001	0.52	0.212 ± 0.003	1.41
		Green	0.102 ± 0.001	0.98	0.134 ± 0.001	0.75	0.169 ± 0.001	0.59	0.252 ± 0.001	0.40	0.297 ± 0.001	0.34
		Sour cherry	1.29 ± 0.03	2.32	1.53 ± 0.02	1.31	1.81 ± 0.01	0.55	1.85 ± 0.02	1.08	2.17 ± 0.02	0.92
		Raspberry	0.084 ± 0.001	1.19	0.118 ± 0.002	1.69	0.141 ± 0.002	1.42	0.148 ± 0.001	0.67	0.151 ± 0.002	1.32
	(-)-Epicatechin	Green	0.147 ± 0.001	0.68	0.245 ± 0.001	0.41	0.38 ± 0.01	2.63	0.63 ± 0.01	1.59	n.d.	/
		Sour cherry	0.233 ± 0.004	1.72	0.296 ± 0.004	1.35	0.371 ± 0.002	0.54	0.367 ± 0.003	0.82	n.d.	/
		Raspberry	n.d.	/	0.299 ± 0.003	1.00	0.311 ± 0.002	0.64	0.347 ± 0.002	0.58	0.424 ± 0.003	0.71
	(-)-Epigallocatechin	Sour cherry	0.074 ± 0.002	2.70	0.077 ± 0.002	2.60	n.d.	/	0.144 ± 0.002	1.39	0.148 ± 0.002	1.35
	Procyanidin B1	Black	0.151 ± 0.001	0.66	0.178 ± 0.001	0.56	n.d.	/	0.261 ± 0.001	0.38	0.358 ± 0.001	0.28
		Raspberry	0.104 ± 0.001	0.96	0.128 ± 0.001	0.78	0.129 ± 0.001	0.77	0.134 ± 0.002	1.49	0.325 ± 0.002	0.62
	Procyanidin B2	Green	0.102 ± 0.001	0.98	0.138 ± 0.001	0.72	0.125 ± 0.001	0.80	n.d.	/	0.197 ± 0.001	0.51
		Sour cherry	0.092 ± 0.001	1.09	0.173 ± 0.003	1.73	n.d.	/	0.189 ± 0.003	1.59	0.222 ± 0.002	0.90
	Procyanidin B3	Green	0.041 ± 0.001	2.44	0.049 ± 0.001	2.04	0.079 ± 0.001	1.26	0.084 ± 0.001	1.19	n.d.	/
		Sour cherry	0.049 ± 0.001	2.04	0.055 ± 0.001	1.82	0.094 ± 0.001	1.06	0.125 ± 0.002	1.60	0.243 ± 0.004	1.65
	Delphinidin-3-*O*-sambubioside	Sour cherry	2.80 ± 0.02	0.71	3.24 ± 0.02	0.62	3.27 ± 0.03	0.92	5.13 ± 0.04	0.78	12.2 ± 0.1	0.82
		Raspberry	3.41 ± 0.04	1.17	5.47 ± 0.04	0.73	7.91 ± 0.05	0.63	6.8 ± 0.1	1.47	12.1 ± 0.1	0.82
	Cyanidin-3-*O*-sambubioside	Sour cherry	1.44 ± 0.01	0.69	1.49 ± 0.01	0.67	1.57 ± 0.01	0.64	2.29 ± 0.01	0.44	n.d.	/
		Raspberry	1.57 ± 0.03	1.91	2.61 ± 0.04	1.53	2.58 ± 0.03	1.16	3.19 ± 0.04	1.25	3.62 ± 0.04	1.10

n.d.: not detected.

delphinidin-3-*O*-sambubioside, for which a regular increasing trend was observed over the 50-day storage period: for caffeic acid, (+)-catechin, and cyanidin-3-*O*-sambubioside at the 50th day of storage, for (-)-epicatechin and rutin at the 40th day of storage, and for procyanidin B1 at the 30th day of storage. The increasing trend contents upon storage at 25°C was noticed in all quantified compounds, except for (+)-catechin on the 40th day of the storage, (-)-epicatechin and procyanidin B1 on the 20th day of storage, and delphinidin-3-*O*-sambubioside at the 50th day of storage. An increasing trend in the quantities of the monitored compounds was observed in general, apart from caffeic acid and cyanidin-3-*O*-sambubioside at the 30th day of storage, rutin at the 50th day of storage, and delphinidin-3-*O*-sambubioside at the 40th day of storage.

In cherry tea extract, nine compounds were quantified and monitored during 50-day storage at different temperatures: gallic acid, caffeic acid, (+)-catechin, (-)-epicatechin, (-)-epigallocatechin, procyanidin B2, procyanidin B3, delphinidin-3-*O*-sambubioside, and cyanidin-3-*O*-sambubioside (Table 4). An increasing trend during the storage time at 4°C with some irregularities was observed for all quantified compounds, except (+)-catechin and delphinidin-3-*O*-sambubioside, where an increase of the content was observed throughout the whole storage period. A more regular increasing trend of the contents of the quantified phenolic compounds was observed during the storage period at 25°C. Exceptions from this regular trend were shown by (-)-epicatechin, procyanidin B2, and procyanidin B3 on the 40th day of storage. A similar situation was seen for the investigated tea and phenolic compounds when the tea bags were kept at 35°C.

The contents of ten phenolic compounds were monitored in green tea under different temperatures during 50-day storage: gallic acid, protocatechuic acid, caffeic acid, rutin, morin, quercetin, (+)-catechin, (-)-epicatechin, procyanidin B2 and procyanidin B3 (Table 4). Only gallic acid and morin showed a regular increasing trend over the storage period at 4°C. Various quantified phenolic compounds were observed upon storage at 25°C: rutin, morin, (+)-catechin, and procyanidin B3. A significantly higher number of irregularities from the increasing trend of the contents of phenolic compounds upon storage at 35°C were noticed. Only (+)-catechin showed regular increasing trend over the 50-day storage period.

Conclusion

The experimental study on aqueous solutions of four types of tea: black, green, sour cherry, and raspberry did not give easily interpretable results due to the complex nature of compounds and processes involved. Extraction is a dominant process at lower elevated temperatures, followed by degradation and other reactions that increase the value of total flavonoids. When tea bags of black and green tea were kept at 4, 25, and 35°C, the maximal value of total flavonoids was observed on the 40th day (except for green tea at 35°C, when it was observed at the 50th day). For sour cherry and raspberry teas, irregular behaviour was observed. Computationally, for the investigated tea samples (black, green, sour cherry, and raspberry), it was found that the optimal temperatures were between 70 - 80°C, and the optimal durations were between 12 - 16 min. The performed approach can be applied to any tea, providing data applicable to the food industry in obtaining the most beneficial effects from drinking tea.

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