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Antioxidant and Antiglycation Properties of Seventeen Fruit Teas Obtained from One Manufacturer

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Abstract: The antioxidant activity of teas depends on the type and quality of the ingredients used in the process of tea production, location of the crops, and manner of the raw material processing. Our study is the first to compare the antioxidant and antiglycation properties of seventeen fruit teas obtained from one manufacturer. We evaluated three different brewing times (3, 5, and 10 min) and two brewing temperatures (70 and 100 °C). We demonstrated that infusions with the longest brewing time reveal the highest antiradical activity, while increased brewing temperature does not significantly affect the assessed parameters. The best antioxidant properties were obtained for the teas made from lemon balm with pear, forest fruits, cranberry with pomegranate, raspberry, and raspberry with linden. Fruit teas owe their high antioxidant activity to the presence of polyphenolic compounds in infusions. Extracts from fruit teas also diminish the oxidation and glycation of albumin in vitro, observed as a decrease in the fluorescence of aromatic amino acids and advanced glycation (AGE) and oxidation (AOPP) protein products levels. In conclusion, in order to prepare fruit teas with the best antioxidant properties, a longer extraction time is needed. The health-promoting properties of dried fruit infusions can be modified by changing the qualitative and quantitative composition of the ingredients.

Keywords: fruit tea; antioxidants; antioxidant activity; albumin glycation; albumin oxidation; oxidative stress

1. Introduction

Tea is currently one of the most popular beverages in the world [1,2]. Every year, the consumption of teas, especially fruit teas, is increasing as a result of raised public awareness of their health-promoting properties. Fruit teas are a mixture of dried fruit, flowers, or leaves. Contrary to popular belief, these products do not contain black tea leaves. The addition of fruit juice concentrates and acidity regulators (e.g., citric acid) improves the taste and aroma of fruit teas [3]. Indeed, fruit tea infusions are successfully replacing sweetened drinks and juices. Interestingly, studies performed in the USA in the years 2011–2016 demonstrated that the highest tea consumption was observed in elderly people aged 51 to 70 years, non-Latin Asians, white people, and people with higher education and income [2].

This is not surprising, because tea has a number of health-promoting properties. One of them is strong antioxidant activity manifested by scavenging reactive oxygen species (ROS).

Oxygen free radicals are atoms or molecules with one unpaired electron or more. They are most often formed under the influence of various physical factors, such as temperature, UV, and ionizing radiation, as well as xenobiotics (e.g., medicines, cigarette smoke, and air pollution) [4–6]. The situation in which the production of free radicals exceeds the body's ability to neutralize them is called oxidative stress (OS). It leads to oxidative damage to proteins, lipids, and DNA, which in turn disturbs cell metabolism and entails the development of cardiovascular [7], immunological [8], neurodegenerative [9,10], and metabolic diseases [11,12], as well as cancer [13,14].

The human body is equipped with specialized antioxidant mechanisms (antioxidant enzymes: catalase, superoxide dismutase, and glutathione peroxidase; low molecular weight antioxidants: uric acid, glutathione, and albumin; and antioxidant vitamins: ascorbic acid and α-Tocopherol) [5,14]. In states with impaired antioxidant barrier and/or overproduction of ROS, the use of extrinsic antioxidants is recommended [8,15]. Exogenous antioxidant compounds are widespread in plant material, animal tissues, and microorganisms. The most important sources of antioxidants are flavonoids, carotenoids, phytosterols, phenolic compounds, and vitamins C and E [16–19]. They occur in particularly large quantities in black, red, and green teas, as well as herbal teas [3,17,20]. The antioxidant abilities of teas depend mainly on the composition of a given tea [3,17,20]. The total content of polyphenols and total antioxidant activity are higher in bearberry tea than in cranberry, mint, chamomile, and even green and black teas [21]. It is assumed that the antioxidant properties of teas may also be determined by the origin of tea ingredients [22]. Moreover, the antioxidant potential of teas of the same composition but obtained from another manufacturer may vary. This is most likely due to different cultivation methods, harvesting period, differences in agronomic procedures, fermentation time, and other treatments typical of the tea-making process of a given manufacturer [22–24]. Interestingly, antioxidant properties of teas also depend on the brewing method [16,25]. It has been shown that the brewing temperature and time are extremely important in the process of phenolic component extraction [17,23,25]. Some studies have confirmed that elevated levels of polyphenolic compounds of black, green, and white tea can be reached by extending the brewing time to more than ten minutes [25–27]. High antioxidant capacity is also demonstrated by herbal tea infusions, and this activity is correlated with the content of polyphenols in a given tea [22,27,28].

While much attention has been paid to traditional leaf teas, there have been few studies assessing the antioxidant properties of infusions made from dried fruit [20]. Moreover, there have been no studies comparing the antioxidant potential of fruit teas with respect to brewing temperature and time. Bearing in mind that the processes of fermentation, drying, sorting, and storage of raw material may affect the quality and properties of teas, we were the first to compare the antioxidant potential of fruit teas produced under the same conditions by one manufacturer. We also evaluated the effect of selected extracts on albumin glycooxidation in vitro.

2. Material and Methods

2.1. Analyzed Fruit Teas

Seventeen fruit teas manufactured by Bi Fix Company (Table 1) were analyzed in our study. According to the producer's declaration, all the teas were prepared under the same technological conditions from the highest quality dried fruit obtained from organic farms in Poland (Document No PL-EKO-01-005192 according to the Article 29 (1) Regulation (EC) No 834/2007). The raw material was stored in a dry, shady, and airy place (18–22 °C). The teas were manufactured according to the following certificates; Integrated Quality Management System ISO 9001, HACCP (Hazard Analysis and Critical Control Points system), BRC (British Retail Consortium), and IFS (International Food Standard). The examined teas are certified as healthy food and have the consumer quality mark (Q-mark).

The composition of the teas, their nutritional value, and indications for use—as declared by the manufacturer—are shown in Table 1.

Table 1. The composition, nutritional value, and indications for use of the analyzed fruit teas as declared by their manufacturer.

Nr	Tea	Composition	Nutritional Value (Per 100 g)					Indications for Use
			Energy Value (kJ/kcal)	Fat (g)	Carbohydrates (g)	Protein (g)	Salt (g)	
1	Chokeberry with Acai Berry	Chokeberry fruit 33%, hibiscus flower, apple, chokeberry juice concentrate, flavoring, acai berry juice concentrate 1%, acidity regulator—citric acid	245/58	0.5	12.7	0.7	0	States of fatigue and general weakness; improves the condition of the heart and vascular system
2	Raspberry with Linden	Raspberry fruit 35%, linden flower 22%, hibiscus flower, chokeberry fruit, flavoring	232/55	0.5	11.6	0.9	0	States of fatigue and exhaustion; supplements the treatment of cold and flu
3	Raspberry	Hibiscus flower, raspberry fruit 20%, black currant fruit, chokeberry fruit, apple, chokeberry juice concentrate, flavoring, acidity regulator—citric acid	213/50	0.6	10.3	0.9	0	Purifies and nourishes the body; supplements the treatment of cold and flu
4	Lemon Balm with Pear	Lemon balm herb 50%, pear 25%, apple, flavoring, acidity regulator—citric acid	249/59	0.1	13.5	0.9	0	Helps relax, calm down; facilitates sleep
5	Honey with Ginger	Black currant fruit, apple, hibiscus flower, chokeberry fruit, orange zest 4%, honey 3%, ginger root 3%, chokeberry juice concentrate, flavorings, lemon zest 2%, cloves, acidity regulator—citric acid	331/78	0.6	17.2	0.9	0	Warms up; soothes nausea; recommended in states of fatigue, tiredness and general weakness
6	Forest Fruits	Hibiscus flower, black currant fruit, chokeberry fruit, apple, raspberry fruit 5%, blueberry fruit 5%, blackberry fruit 5%, elderberry fruit 5%, chokeberry juice concentrate, cranberry fruit 1%, acidity regulator—citric acid	260/61	0.5	13.3	0.8	0	Supports immunity; recommended for smokers and inhabitants of polluted cities
7	Red Orange with Quince	Orange zest 20%, quince fruit 20%, apple, raspberry fruit, chokeberry fruit, chokeberry juice concentrate, flavoring, acidity regulator—citric acid	320/75	0.3	17	0.8	0	Supports immunity; recommended in autumn and winter as well as in states of fatigue, exhaustion and weakened concentration

Table 1. *Cont.*

Nr	Tea	Composition	Nutritional Value (Per 100 g)					Indications for Use
			Energy Value (kJ/kcal)	Fat (g)	Carbohydrates (g)	Protein (g)	Salt (g)	
8	Black Currant with Gooseberry and Cherry	Black currant fruit 30%, hibiscus flower, chokeberry fruit, apple, chokeberry juice concentrate, gooseberry fruit 3%, cherry fruit 3%, flavorings, acidity regulator—citric acid	259/61	0.5	13.3	0.9	0	Improves the condition of the digestive system; strengthens immunity
9	Rosehip with Raspberry	Hibiscus flower, rosehip fruit 25%, chokeberry fruit, apple, raspberry fruit 10%, chokeberry juice concentrate, flavorings, acidity regulator—citric acid	354/84	0.5	18.9	0.9	0	Supports the immunological and digestive systems; recommended in autumn and winter as well as in states of weakened immunity
10	Strawberry with Vanilla	Strawberry fruit 30%, chokeberry fruit, black currant fruit, apple, chokeberry juice concentrate, flavorings, acidity regulator—citric acid, vanilla extract 0.5%	236/56	0.5	12.1	0.7	0	Supports immunity
11	Cranberry	Cranberry fruit 30%, black currant fruit, apple, chokeberry fruit, chokeberry juice concentrate, flavoring, acidity regulator—citric acid	196/46	0.3	10.3	0.6	0	Recommended for people at greater risk of urinary tract infections as well as people with weakened immunity
12	Cranberry with Pomegranate	Hibiscus flower, apple, black currant fruit, chokeberry fruit, cranberry fruit 10%, raspberry fruit, elderberry fruit, chokeberry juice concentrate, pomegranate zest 2%, flavorings, acidity regulator—citric acid	257/61	0.5	13.4	0.7	0	Particularly recommended for people with sensitive urinary system and weakened immunity. Also useful in states of fatigue, exhaustion and weakened concentration.
13	Cranberry with Apple	Hibiscus flower, cranberry fruit 20%, black currant fruit, apple 14%, chokeberry fruit, chokeberry juice concentrate, flavorings, citric acid	249/59	0.4	13.1	0.7	0	Recommended for the proper functioning of the urinary system and in states of weakened immunity

Table 1. *Cont.*

Nr	Tea	Composition	Nutritional Value (Per 100 g)					Indications for Use
			Energy Value (kJ/kcal)	Fat (g)	Carbohydrates (g)	Protein (g)	Salt (g)	
14	Cranberry with Raspberry	Hibiscus flower, cranberry fruit 20%, black currant fruit, raspberry fruit 15%, chokeberry fruit, chokeberry juice concentrate, flavorings, acidity regulator—citric acid	250/59	0.5	12.8	0.8	0	Particularly recommended for people at risk of urinary tract infections and with weakened immunity
15	Raspberry with Chili	Hibiscus flower, chokeberry fruit, raspberry fruit 11.6%, apple, black currant fruit, licorice root 4%, flavoring, acidity regulator—citric acid, ginger root, chili pepper 0.4%	302/71	0.7	15	1.1	0.1	Prevention and treatment of cold. Antipyretic and cleansing effect. Positive effect on the circulatory and digestive systems. Stimulating properties.
16	Ginger with Quince and Strawberry	Hibiscus flower, ginger root 20%, apple, rooibos, quince fruit 5%, flavorings, orange zest, licorice root 4%, acidity regulator—citric acid, strawberry fruit 3%, cinnamon	334/79	0.5	17.4	1.1	0.1	Stimulating and warming-up effect; recommended as an additive in the treatment of cold; removes toxins and heavy metals from the body; reduces the calorific value of food and absorption of sugars; strengthens and nourishes the body; supports the process of blood production.
17	Plum with Chokeberry	Hibiscus flower, chokeberry fruit 20%, raspberry fruit, plum fruit 8%, black currant fruit, apple, flavoring, licorice root 4%, acidity regulator—citric acid, cinnamon	332/78	0.7	16.9	1.2	0.1	Supports metabolism and proper functioning of the digestive system.

2.2. Preparation of Samples

The infusions were prepared on the day the fruit teas were provided by the manufacturer.

Using an analytical balance (laboratory weight KERN PLI 510-3M) accurate to 0.001 g, 1 g of dried tea was weighed and transferred to 200 mL beakers. One-hundred milliliters of distilled water was added to every beaker, and then stirred for 30 s with a glass rod. Next, the beakers were covered with watch glasses. We implemented three different times (3, 5, and 10 min) and two temperatures (70 °C and 100 °C) of brewing. Extraction conditions were determined based on the manufacturer's instructions and literature analysis—we selected the most frequently applied brewing conditions [16,17,25,26,29]. All the variants were prepared in 3 repetitions. After an appropriate time, the infusions were stirred again for 30 s. The content of beakers was poured through membrane filters with a diameter of 0.45 μm (Biosens). After cooling down, the filtrate was transferred to dark test tubes and used immediately for assays.

2.3. Antioxidant Assays

All reagents were purchased from Sigma-Aldrich (Nümbrecht, Germany and/or Saint Louis, MO, USA). The absorbance was measured using Infinite M200 PRO Multimode Microplate Reader Tecan (Tecan Group Ltd., Männedorf, Switzerland). The measurements were performed in triplicate samples and the results were standardized to 1 g of dry weight (DW).

2.3.1. Total Antioxidant Capacity (TAC)

The determination of TAC was based on the oxidation of ferrous ion to ferric ion in the presence of oxidants contained in the sample. Changes in absorbance were determined at 660 nm wavelength, and TAC level was calculated from the calibration curve for Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid). The value was expressed in nmol Trolox/g DW [30].

2.3.2. Radical Scavenging Activity Assay (DPPH)

The antioxidant activity of every sample was measured with DPPH (1,1-diphenyl-2-picrylhydrazyl). This compound becomes discolored in the presence of antioxidants, which was the basis for spectrophotometric measurement at 515 nm wavelength. The value was expressed as nmol Trolox/g DW [31].

2.3.3. Ferric Reducing Antioxidant Power (FRAP)

FRAP is based on the reduction of an iron (III) ion to an iron (II) ion, resulting in the formation of a colorful ferrous-tripyridyltriazine complex. The reaction occurs in an acidic environment. Absorbance was measured at 592 nm wavelength by comparing each tested sample to a sample with known ferrous ion concentration. The value was expressed as μmol Fe (II)/g DW [32].

2.3.4. Total Phenolic Content (TPC)

The content of polyphenols in every sample was assayed according to the Folin–Ciocalteu method. It is based on the reduction of phospho-molybdate heteropoly acid Mo(VI) center in the heteropoly complex to Mo(V), which is evidenced by blue coloration of the sample. Absorbance of the samples was measured at 750 nm wavelength. The value was expressed as μg GAE/g DW) [31].

2.3.5. Total Oxidant Status (TOS)

The test was based on the oxidation of a ferrous ion to an iron ion that forms a colored complex with o-cresosulfonphthalein-3,3′-bis(sodium methyliminodiacetate) (xylenol orange) in an acidic medium. The content of oxidants in the sample was proportional to the intensity of color measured according to the spectrophotometric method. The value was presented as μmol H_2O_2/g DW [33].

2.4. Oxidative Modifications of Albumin

2.4.1. Experimental Model

Bovine serum albumin (BSA, 96% purity) was dissolved in phosphate-buffered saline (PBS, pH 7.4). The concentration of albumin was 40 mg/mL, which reflects its physiological content in human blood. BSA was incubated with chloramine T (20 mM), chloramine T + additivies (0.1/1; v:v), or PBS alone (PBS, pH 7.4) [34]. Vitamin C (ascorbic acid, 10 mM) was used as a known protein oxidation inhibitor. The concentrations of various additives were selected based on other in vitro studies [34,35]. After thorough mixing on vortex and incubation in closed vials (37 °C, 50 rpm shaking, darkness) samples were taken for further analysis. Two incubation times were applied: 30 and 60 min [34]. The experiments were performed in three series, each time in triplicate. Five tea extracts with the best antioxidant properties were selected for analysis: lemon balm with pear, forest fruits, cranberry with pomegranate, raspberry, and raspberry with linden. The results are presented as % of control (BSA + chloramine T).

2.4.2. Protein Glycooxidation Products

The content of albumin glycooxidation products was evaluated by fluorimetric methods [36]. Fluorescence was measured at 330/415 nm (dityrosine), 325/434 nm (*N*'-formylkynurenine), 365/480 nm (kynurenine), 95/340 nm (tryptophan), and 325/440 nm (advanced glycation end products (AGE)).

2.4.3. Advanced oxidation protein products (AOPP)

AOPP concentration was assessed colorimetrically by measuring the oxidative capacity of iodine ion [37]. Fifty milliliters of the sample was incubated with 150 μL of 0.1 M sodium phosphate buffer (pH 7.4), 10 μL of 1.16 M sodium iodide, and 20 μL of glacial acetic acid. Before mixing, the derivatives were measured at 340 nm.

2.5. Statistical Analysis

The obtained data were analyzed in the statistical program GraphPad Prism 8.3.0 for MacOS (GraphPad Software, Inc. La Jolla, CA, USA). Normality of distribution was assessed with the Shapiro–Wilk test. The one-way analysis of variance (ANOVA), two-way ANOVA, and Tukey's HSD tests were used to compare quantitative variables. Multiplicity adjusted p value was also calculated. The results were presented as mean ± SD. Correlations between the parameters were evaluated using Pearson correlation coefficient. $p < 0.05$ was considered statistically significant.

3. Results

3.1. Antioxidant Assays

A number of methods are used to assess the antioxidant properties of food and beverages. However, it is only the total antioxidant activity that informs about interactions between all individual antioxidants. Therefore, in our study we evaluated the total antioxidant capacity (TAC), radical scavenging activity (DPPH), ferric reducing antioxidant power (FRAP), total phenolic content (TPC), and total oxidant status (TOS).

3.1.1. Total Antioxidant Capacity (TAC)

Total antioxidant capacity of the tested teas is contained in the range from 0.79 ± 0.03 nmol Trolox/g DW (Black currant with gooseberry and cherry, T = 70 °C, t = 3 min) to 2.40 ± 0.16 nmol Trolox/g DW (Lemon balm with pear, T = 100 °C, t = 10 min). Moreover, Rosehip with raspberry (2.34 ± 0.33 nmol Trolox/g DW) as well as Forest fruits (2.34 ± 0.43 nmol Trolox/g DW), Cranberry with pomegranate (2.16 ± 0.15 nmol Trolox/g DW), and Raspberry (2.16 ± 0.10 nmol Trolox/g DW) teas were also characterized by high TAC values. All teas (except two) reached their highest TAC at 100 °C after 10 min of brewing, whereas Lemon balm with pear reached its highest TAC at T = 70 °C after 10 min, and Red orange with quince reached its highest TAC at T = 100 °C after 5 min. Generally, the lowest TAC values were found in teas with the lowest temperature and the shortest time (T = 70 °C, t = 3 min) of brewing (Table 2).

Table 2. Total antioxidant capacity (TAC) in fruit tea infusions. ^{a} $p < 0.05$ vs. 3 min 70 °C; ^{b} $p < 0.05$ vs. 3 min 100 °C; ^{c} $p < 0.05$ vs. 5 min 70 °C; ^{d} $p < 0.05$ vs. 5 min 100 °C; ^{e} $p < 0.05$ vs. 10 min 70 °C.

Tea	TAC (nmol Trolox/g DW)						
	3 min 70 °C	3 min 100 °C	5 min 70 °C	5 min 100 °C	10 min 70 °C	10 min 100 °C	p Value
Chokeberry with acai berry	1.40 ± 0.21	1.51 ± 0.13	1.68 ± 0.22	1.84 ^{a} ± 0.11	1.70 ± 0.20	2.14 ^{abe} ± 0.12	0.0029
Raspberry with linden	0.92 ± 0.07	1.21 ^{a} ± 0.09	1.37 ^{a} ± 0.13	1.43 ^{ab} ± 0.18	1.57 ^{ab} ± 0.10	1.60 ^{abc} ± 0.12	0.0002
Raspberry	1.45 ± 0.16	1.57 ± 0.15	1.77 ^{a} ± 0.12	1.80 ^{a} ± 0.14	1.85 ^{ab} ± 0.16	2.16 ^{abcde} ± 0.10	0.0008
Lemon balm with pear	1.95 ± 0.12	2.06 ± 0.10	2.35 ^{a} ± 0.16	2.27 ^{a} ± 0.11	2.29 ^{ab} ± 0.14	2.40 ^{a} ± 0.16	0.0097
Honey with ginger	1.49 ± 0.13	1.48 ± 0.15	1.51 ± 0.12	1.63 ± 0.20	1.76 ^{ab} ± 0.14	1.76 ^{ab} ± 0.16	0.1098
Forest fruits	1.03 ± 0.12	1.30 ± 0.25	1.48 ± 0.24	1.52 ± 0.13	1.86 ^{ab} ± 0.11	2.34 ^{abcd} ± 0.43	0.0004
Red orange with quince	0.94 ± 0.11	1.18 ± 0.17	1.35 ^{a} ± 0.10	1.61 ^{ab} ± 0.18	1.43 ^{a} ± 0.17	1.60 ^{ab} ± 0.19	0.0015
Black currant with gooseberry and cherry	0.79 ± 0.03	1.17 ^{a} ± 0.16	1.30 ^{a} ± 0.14	1.26 ^{a} ± 0.19	1.31 ^{a} ± 0.10	1.44 ^{ab} ± 0.11	0.001
Rosehip with raspberry	1.80 ± 0.31	1.35 ± 0.19	1.69 ^{a} ± 0.19	1.73 ^{a} ± 0.17	1.75 ^{a} ± 0.16	2.34 ^{abde} ± 0.33	0.0011
Strawberry with vanilla	1.06 ± 0.23	1.08 ± 0.10	1.43 ^{a} ± 0.17	1.56 ^{ab} ± 0.16	1.66 ^{ab} ± 0.10	2.23 ^{abcde} ± 0.34	0.0001
Cranberry	1.07 ± 0.14	1.27 ± 0.15	1.27 ± 0.13	1.50 ± 0.13	1.51 ± 0.15	1.75 ± 0.17	0.0025
Cranberry with pomegranate	1.18 ± 0.15	1.36 ± 0.21	1.65 ^{a} ± 0.17	1.76 ^{ab} ± 0.13	1.74 ^{ab} ± 0.26	2.16 ^{abcde} ± 0.15	0.0004
Cranberry with apple	1.31 ± 0.15	1.26 ± 0.17	1.32 ± 0.12	1.56 ± 0.13	1.55 ± 0.15	2.04 ± 0.12	0.0002
Cranberry with raspberry	1.19 ± 0.13	1.31 ± 0.18	1.51 ^{a} ± 0.19	1.76 ^{ab} ± 0.16	1.82 ^{abc} ± 0.17	1.98 ^{abc} ± 0.17	0.0005
Raspberry with chili	1.39 ± 0.22	1.58 ± 0.11	1.56 ± 0.12	1.58 ± 0.11	1.57 ± 0.18	1.83 ^{ab} ± 0.11	0.0774
Ginger with quince and strawberry	1.03 ± 0.15	1.23 ± 0.10	1.33 ± 0.12	1.42 ± 0.13	1.68 ± 0.18	2.05 ± 0.47	0.0023
Plum with chokeberry	0.98 ± 0.15	1.19 ± 0.16	1.40 ^{a} ± 0.21	1.53 ^{ab} ± 0.23	1.67 ^{a} ± 0.18	1.72 ^{ab} ± 0.20	0.0002
Column mean ± SD	1.23 ± 0.16	1.36 ± 0.15	1.53 ± 0.16	1.63 ± 0.15	1.70 ± 0.16	1.98 ± 0.20	
			Two-way ANOVA				
Time (% of variation)				40.15			<0.0001
Temperature (% of variation)				6.34			0.0014
Interaction (% of variation)				1.25			0.3447

The two-way analysis of variance (ANOVA) showed that individual infusions differ significantly both in terms of brewing temperature ($p = 0.0014$) and time ($p < 0.0001$) (Table 2).

3.1.2. Radical Scavenging Activity (DPPH) Assay

DPPH values of the teas varied from 129.90 ± 26.91 nmol Trolox/g DW (Cranberry, T = 70 °C, t = 3 min) to 549.10 ± 44.69 nmol Trolox/g DW (Lemon balm with pear, T = 100 °C, t = 10 min). High DPPH values were also achieved by the following teas; Forest fruits (467.70 ± 15.75 nmol Trolox/g DW), Cranberry with pomegranate (453.80 ± 35.46 nmol Trolox/g DW), Raspberry with linden (455.90 ± 43.99 nmol Trolox/g DW), and Raspberry (450.40 ± 41.79 nmol Trolox/g DW). Except the tea Lemon balm with pear, which reached the lowest DPPH value when brewed at 100 °C for 5 min, all teas reached the lowest DPPH values at the lowest brewing temperature (70 °C) and the shortest time (3 min). Eleven teas revealed the highest DPPH values at the brewing temperature of 100 °C and time of 10 min. Raspberry with linden and Cranberry with pomegranate teas demonstrated the highest DPPH values at 70 °C and 10 min of brewing time, Lemon balm with pear and Strawberry with vanilla teas – in T = 70 °C after 5 min of brewing, and Chokeberry with acai berry achieved the highest DPPH values at the brewing temperature of 100 °C after 5 min of brewing (Table 3).

The two-way analysis of variance (ANOVA) demonstrated that individual infusions differ statistically only in terms of brewing time ($p < 0.0001$) (Table 3).

Table 3. DPPH radical (α-diphenyl-β-picrylhydrazyl) scavenging activity in fruit tea infusions. ^{a} $p < 0.05$ vs. 3 min 70 °C; ^{b} $p < 0.05$ vs. 3 min 100 °C; ^{c} $p < 0.05$ vs. 5 min 70 °C; ^{d} $p < 0.05$ vs. 5 min 100 °C; ^{e} $p < 0.05$ vs. 10 min 70 °C.

Tea	DPPH (nmol Trolox/g DW)						*p* Value
	3 min 70 °C	**3 min 100 °C**	**5 min 70 °C**	**5 min 100 °C**	**10 min 70 °C**	**10 min 100 °C**	
Chokeberry with acai berry	241.1 ± 29.5	268.3 ± 26.0	333.8 ^{a} ± 32.1	354.6 ^{a} ± 34.6	351.4 ^{a} ± 34.3	344.0 ^{a} ± 31.1	0.0026
Raspberry with linden	268.5 ± 24.4	315.9 ± 30.2	311.0 ± 33.0	349.2 ^{a} ± 34.1	455.9 ^{abcd} ± 44.0	452.8 ^{abcd} ± 46.6	0.0001
Raspberry	262.7 ± 29.9	338.7 ^{a} ± 35.6	339.2 ^{a} ± 36.4	355.1 ± 36.9	446.9 ^{abc} ± 43.7	450.4 ^{abcde} ± 41.8	0.0004
Lemon balm with pear	547.3 ± 45.1	538.9 ± 34.7	545.7 ± 41.2	544.2 ± 39.8	544.8 ± 39.8	549.1 ± 44.7	0.0217
Honey with ginger	218.6 ± 32.2	260.9 ± 48.5	274.2 ± 34.2	348.0 ^{abc} ± 28.1	356.3 ^{abc} ± 33.2	393.3 ^{abc} ± 25.2	0.0003
Forest fruits	283.6 ± 23.8	289.5 ± 20.0	364.1 ^{ab} ± 34.0	380.7 ^{ab} ± 70.5	388.6 ^{ab} ± 43.4	467.7 ^{abcde} ± 15.8	0.0008
Red orange with quince	205.0 ± 21.9	234.9 ± 11.3	257.5 ^{a} ± 33.2	333.2 ^{abc} ± 29.5	402.6 ^{abcd} ± 12.4	421.2 ^{abcd} ± 48.6	<0.0001
Black currant with gooseberry and cherry	169.6 ± 10.1	267.2 ^{a} ± 21.9	296.8 ^{a} ± 68.2	298.0 ^{a} ± 35.0	406.9 ^{abcd} ± 30.1	431.5 ^{abcd} ± 24.0	<0.0001
Rosehip with raspberry	316.4 ± 52.6	385.3 ^{a} ± 20.4	413.1 ^{ab} ± 48.9	433.2 ^{a} ± 15.3	433.7 ^{a} ± 17.0	448.7 ^{a} ± 42.3	0.0078
Strawberry with vanilla	181.7 ± 62.9	206.9 ± 20.7	305.8 ^{ab} ± 25.6	261.1 ^{a} ± 28.7	285.5 ^{ab} ± 25.4	261.5 ^{a} ± 24.3	0.0066
Cranberry	129.9 ± 26.9	206.1 ^{a} ± 19.6	332.2 ^{ab} ± 28.8	344.9 ^{ab} ± 38.0	381.0 ^{ab} ± 25.4	385.0 ^{ab} ± 37.7	<0.0001
Cranberry with pomegranate	246.3 ± 42.0	368.4 ^{a} ± 30.7	365.5 ^{a} ± 31.7	402.4 ^{a} ± 35.0	453.8 ^{abc} ± 35.5	453.2 ^{abc} ± 18.0	<0.0001
Cranberry with apple	177.7 ± 25.5	232.3 ± 24.6	271.7 ^{a} ± 38.9	342.5 ^{abc} ± 40.6	296.6 ^{ab} ± 26.7	379.8 ± 38.6	<0.0001
Cranberry with raspberry	208.4 ± 28.3	229.8 ± 21.2	298.9 ± 32.2	339.9 ± 27.8	365.7 ± 29.7	370.8 ± 22.1	<0.0001
Raspberry with chili	173.2 ± 33.3	251.5 ^{a} ± 28.5	250.7 ^{a} ± 24.6	262.5 ^{a} ± 27.3	329.2 ^{abcd} ± 21.7	323.1 ^{abcd} ± 20.9	0.0001
Ginger with quince and strawberry	181.7 ± 18.0	193.7 ± 18.9	223.8 ^{a} ± 20.3	264.7 ^{abc} ± 23.4	250.5 ^{ab} ± 22.7	336.3 ^{abd} ± 24.7	<0.0001
Plum with chokeberry	173.4 ± 25.4	258.2 ± 21.8	286.8 ± 31.6	301.2 ± 28.2	370.4 ± 22.6	402.3 ± 31.2	0.0004
Column mean ± SD	234.42 ± 31.28	285. 09 ± 25.56	321.81 ± 34.99	347.96 ± 33.69	383.52 ± 29.86	404.16 ± 31.62	
	Two-way ANOVA						
Time (% of variation)	31.03						<0.0001
Temperature (% of variation)	2.54						0.066
Interaction (% of variation)	0.31						0.81

3.1.3. Ferric Reducing Antioxidant Power (FRAP)

The highest FRAP value was noted at 100 °C after 10 min of brewing the Raspberry with linden tea (8863.00 ± 536.40 µmol Fe(II)/g DW), and the lowest at the brewing temperature of 70 °C and time of 3 min for the tea Raspberry (1805.00 ± 588.60 µmol Fe(II)/g DW). The following teas also had a high FRAP value; Lemon balm with pear (8699.00 ± 598.30 µmol Fe(II)/g DW), Forest fruits (8651.00 ± 273.50 µmol Fe(II)/g DW), Cranberry with pomegranate (8515.00 ± 115.30 µmol Fe(II)/g DW), and Rosehip with raspberry (8501.00 ± 482.80 µmol Fe(II)/g DW). Except for Cranberry tea, in which the lowest FRAP value was observed when brewed at 100 °C for 3 min, all teas achieved the lowest FRAP values at the lowest temperature and the shortest brewing time (i.e., T = 70 °C, t = 3 min). Ten teas reached the highest FRAP values when brewed at the highest temperature for the longest time (i.e., T = 100 °C, t = 10 min). The teas Chokeberry with acai berry, Forest fruits, Red orange with quince, Rosehip with raspberry, and Strawberry with vanilla achieved the highest FRAP values when brewed at 70 °C for 10 min. The tea Ginger with quince and strawberry had the highest FRAP values at T = 100 °C and brewing time of 5 min (Table 4).

Table 4. Ferric Reducing Antioxidant Power (FRAP) in fruit tea infusions. ^{a} $p < 0.05$ vs. 3 min 70 °C; ^{b} $p < 0.05$ vs. 3 min 100 °C; ^{c} $p < 0.05$ vs. 5 min 70 °C; ^{d} $p < 0.05$ vs. 5 min 100 °C; ^{e} $p < 0.05$ vs. 10 min 70 °C.

Tea	FRAP (µmol Fe (II)/g DW)						
	3 min 70 °C	**3 min 100 °C**	**5 min 70 °C**	**5 min 100 °C**	**10 min 70 °C**	**10 min 100 °C**	***p* Value**
Chokeberry with acai berry	5976 ± 220	6366 ± 255	7108 ^{ab} ± 134	7208 ^{ab} ± 216	7501 ^{ab} ± 243	8264 ^{abcde} ± 649	<0.0001
Raspberry with linden	7181 ± 196	7500 ± 196	8280 ^{a} ± 617	8657 ^{ac} ± 519	7707 ^{d} ± 594	8863 ^{ace} ± 536	0.0055
Raspberry	1805 ± 589	3295 ^{a} ± 127	3508 ^{a} ± 947	4309 ^{ab} ± 517	4556 ^{abc} ± 274	5564 ^{abcde} ± 403	<0.0001
Lemon balm with pear	7191 ± 556	6980 ± 219	7595 ± 144	8107 ^{ab} ± 190	8476 ^{abc} ± 479	8699 ^{abc} ± 598	0.0011
Honey with ginger	5755 ±530	6249 ± 226	6709 ^{a} ± 132	6749 ^{ab} ± 146	7289 ^{abcd} ± 212	7516 ^{abcd} ± 192	<0.0001
Forest fruits	7506 ± 922	7647 ± 349	8398 ± 509	7537 ± 654	8651 ^{abc} ± 274	8413 ± 191	0.0729
Red orange with quince	7414 ± 422	7737 ± 420	7549 ± 110	8217 ^{a} ± 485	8240 ^{a} ± 535	8216 ^{a} ± 191	0.0712
Black currant with gooseberry and cherry	7312 ± 223	7282 ± 118	7670 ± 268	7606 ± 384	8090 ^{abcd} ± 143	8389 ^{abcd} ± 124	0.0004
Rosehip with raspberry	5505 ± 124	7664 ± 286	7716 ± 183	7271 ^{a} ± 524	8501 ^{abd} ± 483	8328 ^{ad} ± 239	<0.0001
Strawberry with vanilla	6776 ±112	6871 ± 324	7132 ^{a} ± 191	7819 ^{abc} ± 119	7855 ^{abc} ± 244	8466 ^{abcde} ± 152	<0.0001
Cranberry	6379 ± 118	7097 ± 127	7262 ^{a} ± 228	7336 ^{a} ± 277	8254 ^{abcd} ± 459	7915 ^{abcd} ± 229	<0.0001
Cranberry with pomegranate	7118 ± 112	7257 ± 101	7406 ±103	8001 ^{abc} ± 126	8515 ^{abc} ± 115	8120 ^{abc} ± 529	<0.0001
Cranberry with apple	7512 ± 439	7602 ± 120	7617 ± 115	7795 ± 107	8283 ^{abcd} ± 313	8190 ^{abc} ± 140	0.0074
Cranberry with raspberry	6195 ± 291	6745 ^{a} ± 127	7084 ^{ab} ± 131	7475 ^{abc} ± 213	7801 ^{abcd} ± 137	7984 ^{abcd} ± 111	<0.0001
Raspberry with chili	6760 ± 603	7285 ± 244	7556 ^{a} ± 108	7548 ^{a} ± 262	8022 ^{ab} ± 115	8314 ^{abcd} ± 133	0.0006
Ginger with quince and strawberry	6887 ± 243	7584 ^{a} ± 182	7692 ^{a} ± 126	8607 ^{abc} ± 584	8488 ^{abc} ± 462	8236 ^{abcd} ± 155	0.0004
Plum with chokeberry	5918 ± 258	6296 ± 243	6459 ± 212	6820 ± 268	7200 ± 223	7620 ± 241	<0.0001
Column mean ± SD	6422.94 ± 350.47	6909.24 ± 215.53	7220.06 ± 250.47	7474.24 ± 328.88	7848.76 ± 312.06	8064.53 ± 283.12	
			Two-way ANOVA				
Time (% of variation)			18.15				0.0001
Temperature (% of variation)			1.29				0.2332
Interaction (% of variation)			0.06				0.9662

The two-way analysis of variance (ANOVA) variance showed that individual infusions differ significantly only in terms of brewing time ($p = 0.0001$) (Table 4).

3.1.4. Total Phenolic Content (TPC)

TPC values ranged from 699.70 ± 191.60 µg GAE/g DW (Cranberry, T = 70 °C, t = 3 min) to 51315.00 ± 978.60 µg GAE/g DW (Lemon balm with pear, T = 100 °C, t = 10 min). High TPC values were also achieved with the teas Cranberry with pomegranate (17153.00 ± 518.70 µg GAE/g DW), Forest fruits (13928.00 ± 691.80 µg GAE/g DW), Raspberry with linden (12501.00 ± 1779.00 µg GAE/g DW), and Raspberry (9005.00 ± 122.40 µg GAE/g DW). All teas had the highest TPC values when brewed at 100 °C for 10 min, and the lowest at 70 °C for 3 min (Table 5).

Table 5. Total phenolic content (TPC) in fruit tea infusions. [a] $p < 0.05$ vs. 3 min 70 °C; [b] $p < 0.05$ vs. 3 min 100 °C; [c] $p < 0.05$ vs. 5 min 70 °C; [d] $p < 0.05$ vs. 5 min 100 °C; [e] $p < 0.05$ vs. 10 min 70 °C.

Tea	TPC (µg GAE/g DW)						
	3 min 70 °C	3 min 100 °C	5 min 70 °C	5 min 100 °C	10 min 70 °C	10 min 100 °C	p Value
Chokeberry with acai berry	1416 ± 316	1715 ± 573	3401 [ab] ± 155	4443 [abc] ± 764	3986 [ab] ± 675	5632 ± 640 [abcd]	<0.0001
Raspberry with linden	1215 ± 193	1379 ± 590	1589 ± 334	2816 ± 225	7438 [abcd] ± 1276	12501 ± 1779 [abcde]	<0.0001
Raspberry	1274 ± 124	1319 ± 155	4114 [ab] ± 172	5369 [abc] ± 707	8563 [abcd] ± 503	9005 ± 122 [abcd]	<0.0001
Lemon balm with pear	22145 ± 394	25515 [a] ± 513	29610 [ab] ± 543	34590 [abc] ± 615	37123 [abcd] ± 519	51315 ± 979 [abcde]	<0.0001
Honey with ginger	2444 ± 150	2863 ± 733	2972 ± 231	3463 [a] ± 287	9529 [abcd] ± 103	4844 ± 554 [abcde]	<0.0001
Forest fruits	2064 ± 359	3958 [a] ± 546	3728 [a] ± 692	9486 [abc] ± 760	12036 [abcd] ± 455	13928 ± 692 [abcde]	<0.0001
Red orange with quince	1868 ± 152	2670 ± 476	3453 ± 123	4499 ± 807	6958 ± 684	11680 ± 609	<0.0001
Black currant with gooseberry and cherry	1669 ± 213	3271 [a] ± 223	3803 [a] ± 728	3672 [a] ± 558	6221 [abcd] ± 520	6406 [abcd] ± 822	<0.0001
Rosehip with raspberry	1479 ± 137	1341 ± 122	1466 ± 394	2125 [abc] ± 615	2278 [abc] ± 318	6734 [abcde] ± 273	<0.0001
Strawberry with vanilla	960 ± 135	1149 ± 115	1924 [ab] ± 313	2108 [ab] ± 294	2898 [abc] ± 133	3260 [abcd] ± 254	<0.0001
Cranberry	699 ± 192	1302 ± 110	2349 [a] ± 246	2994 [ab] ± 980	2950 [ab] ± 936	6322 [abcde] ± 703	<0.0001
Cranberry with pomegranate	5929 ± 887	8056 [a] ± 303	6996 ± 854	9580 [abc] ± 980	13705 [abcd] ± 564	17153 [abcde] ± 519	<0.0001
Cranberry with apple	1464 ± 118	1517 [a] ± 158	2557 [a] ± 251	3881 [abc] ± 583	3531 [abc] ± 707	4371 [abce] ± 275	<0.0001
Cranberry with raspberry	1123 ± 387	1233 ± 467	1835 ± 171	2891 [abc] ± 411	3193 [abc] ± 988	3510 [abc] ± 187	0.0002
Raspberry with chili	1046 ± 386	1208 ± 120	1374 ± 193	1955 [a] ± 428	2670 [abc] ± 296	2433 [abc] ± 795	0.0022
Ginger with quince and strawberry	1357 ± 136	1105 ± 309	1472 [a] ± 299	2253 [abc] ± 682	3011 [abc] ± 646	3832 [abcde] ± 109	<0.0001
Plum with chokeberry	1200 ± 183	1298 ± 202	1345 ± 198	1523 ± 231	1570 ± 242	1860 ± 231	<0.0001
Column mean ± SD	3009.5 ± 262.47	3582.29 ± 336.18	4352.24 ± 346.88	5744 ± 583.94	7509.41 ± 562.65	9693.29 ± 561.35	
Two-way ANOVA							
Time (% of variation)	8.48						0.0178
Temperature (% of variation)	0.90						0.35
Interaction (% of variation)	0.13						0.94

The two-way analysis of variance (ANOVA) demonstrated that individual infusions differ significantly only in terms of the brewing time (p = 0.0178) (Table 5).

3.1.5. Total Oxidant Status (TOS)

The lowest TOS value was 1.71 ± 0.37 µmol H2 O2/g DW and it was observed for Lemon balm with pear brewed at 100 °C for 10 min. Low TOS values were also achieved by the teas Cranberry with pomegranate (1.80 ± 1.14 µmol H_2O_2/g DW), Forest fruits (2.02 ± 0.25 µmol H_2O_2/g DW), Raspberry with linden (3.03 ± 0.27µmol H_2O_2/g DW), and Raspberry (3.31 ± 0.25 µmol H_2O_2/g DW). The highest TOS value, which was 21.49 ± 9.74 µmol H_2O_2/g DW, was found in Rosehip with raspberry. The highest TOS values were observed at 100 °C and the shortest brewing time, while the lowest were obtained at the highest brewing temperature and the shortest time (Table 6).

Table 6. Total oxidant status (TOS) in fruit tea infusions. [a] $p < 0.05$ vs. 3 min 70 °C; [b] $p < 0.05$ vs. 3 min 100 °C; [c] $p < 0.05$ vs. 5 min 70 °C; [d] $p < 0.05$ vs. 5 min 100 °C; [e] $p < 0.05$ vs. 10 min 70 °C.

Tea	TOS (μmol H_2O_2/g DW)						
	3 min 70 °C	3 min 100 °C	5 min 70 °C	5 min 100 °C	10 min 70 °C	10 min 100 °C	*p* Value
Chokeberry with acai berry	10.00 ± 1.82	12.80 [a] ± 1.11	8.40 [a] ± 0.89	7.13 [ab] ± 0.49	5.96 [abc] ± 0.12	5.28 [abcd] ± 0.43	<0.0001
Raspberry with linden	5.50 ± 0.90	12.34 [a] ± 2.68	5.00 [a] ± 0.28	4.82 [a] ± 0.77	3.74 [a] ± 0.25	3.03 [a] ± 0.27	<0.0001
Raspberry	6.27 ± 0.74	8.30 [a] ± 0.43	6.21 [a] ± 0.92	5.41 [a] ± 0.67	4.29 [abcd] ± 0.11	3.31 [abcd] ± 0.25	<0.0001
Lemon balm with pear	4.33 ± 0.40	8.50 [a] ± 0.85	3.46 [a] ± 0.27	2.79 [ab] ± 0.64	2.30 [abc] ± 0.16	1.71 [abcd] ± 0.37	<0.0001
Honey with ginger	10.58 ± 1.05	13.91 [a] ± 1.29	9.35 [a] ± 0.37	8.27 [ab] ± 0.46	7.47 [abc] ± 0.22	4.60 [abcde] ± 0.37	<0.0001
Forest fruits	3.34 ± 0.22	6.05 [a] ± 0.95	3.09 [a] ± 0.95	2.97 [a] ± 0.46	2.51 [a] ± 0.25	2.02 [ab] ± 0.25	<0.0001
Red orange with quince	7.38 ± 0.55	10.55 [a] ± 1.20	6.88 [a] ± 0.86	6.14 [a] ± 0.31	6.11 [a] ± 0.89	4.48 [a] ± 0.12	<0.0001
Black currant with gooseberry and cherry	8.24 ± 0.49	9.81 [a] ± 0.83	6.88 [ab] ± 0.12	5.04 [abc] ± 0.37	4.79 [abc] ± 0.18	4.92 [abc] ± 0.50	<0.0001
Rosehip with raspberry	7.38 ± 2.96	21.49 [a] ± 9.74	7.16 [a] ± 0.83	6.61 [a] ± 0.77	4.27 [a] ± 0.59	3.67 [abcde] ± 0.73	0.0023
Strawberry with vanilla	9.20 ± 1.94	19.73 ± 4.96	6.32 [a] ±0.11	5.19 [a] ± 0.46	5.13 [a] ± 0.77	3.71 [ac] ± 0.89	0.0008
Cranberry	12.77 ± 1.51	19.05 [a] ± 2.68	8.04 [ab] ± 0.97	7.07 [ab] ± 0.62	5.71 [ab] ± 0.62	5.75 [ab] ± 0.10	<0.0001
Cranberry with pomegranate	9.32 ± 1.14	12.28 ± 1.39	7.72 [a] ± 0.81	5.83 [abc] ± 0.13	3.90 [abcd] ± 0.71	1.80 [abcde] ± 1.14	<0.0001
Cranberry with apple	9.66 ± 1.29	12.06 [a] ± 1.03	8.49 [a] ± 0.86	6.88 [abc] ± 0.55	6.05 [abc] ± 0.15	6.02 [abc] ± 0.43	<0.0001
Cranberry with raspberry	6.27 ± 0.62	9.72 [a] ± 1.11	6.02 [a] ± 0.37	5.28 [a] ± 0.25	4.91 [abc] ± 0.62	4.54 [abc] ± 0.12	<0.0001
Raspberry with chili	8.67 ± 0.62	10.58 [a] ± 0.80	7.16 [ab] ± 0.22	6.48 [ab] ± 0.15	5.44 [abc] ± 0.15	4.23 [abcde] ± 0.68	<0.0001
Ginger with quince and strawberry	7.01 ± 0.12	10.18 [a] ± 1.94	5.84 [a] ± 0.13	5.65 [a] ± 0.31	4.88 [ab] ± 0.34	4.26 [ab] ± 1.33	0.0001
Plum with chokeberry	7.37 ± 0.52	9.95 ± 0.76	6.75 ± 0.32	6.20 ± 00.36	6.05 ± 0.48	4.24 ± 0.56	<0.0001
Column mean ± SD	7.84 ± 0.99	12.19 ± 1.99	6.63 ± 0.55	5.75 ± 0.45	4.84 ± 0.39	3.97 ± 0.5	
Two-way ANOVA							
Time (% of variation)	43.83						<0.0001
Temperature (% of variation)	1.44						0.0853
Interaction (% of variation)	12.04						<0.0001

The two-way analysis of variance (ANOVA) indicated that individual infusions differ significantly both in terms of brewing time ($p < 0.0001$) and the brewing temperature–time interaction ($p < 0.0001$) (Table 6).

3.1.6. Correlations

Correlations between the analyzed parameters are presented in Figure 1.

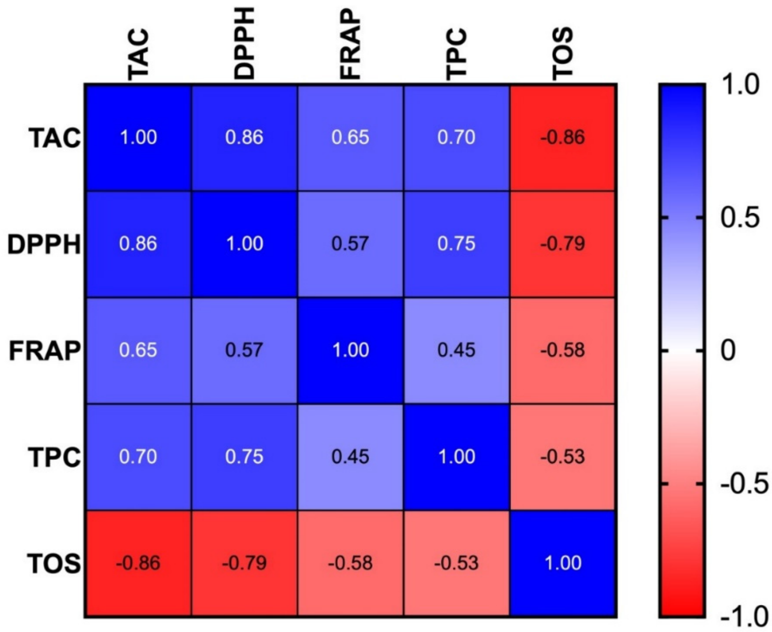

Figure 1. Heatmap of correlations between the analyzed antioxidant parameters. DPPH—Radical scavenging activity assay; FRAP—Ferric Reducing Antioxidant Power; TAC—Total antioxidant capacity; TOS—Total oxidant status; TPC—Total phenolic content.

A positive correlation was observed between TPC concentration and the levels of TAC, DPPH, and FRAP, where the Pearson correlation coefficient for each of the teas was, respectively, 0.7, 0.75, and 0.45 at the statistical significance level of $p < 0.0001$. Among the parameters determining total antioxidant activity we observed a very strong positive correlation between TAC and DPPH ($r = 0.86$, $p < 0.0001$) and a weaker one between TAC and FRAP ($r = 0.65$, $p < 0.0001$). As excepted, there was also a negative correlation between TOS concentration and other parameters ($p < 0.0001$) (Figure 1).

3.2. Oxidative Modifications of Albumin

In the next stage of the experiment, we evaluated the effect of selected extracts of fruit teas on protein glycooxidation in vitro. Five tea extracts with the best antioxidant properties were selected for analysis: lemon balm with pear, forest fruits, cranberry with pomegranate, raspberry, and raspberry with linden. The results are presented as % of control (BSA + chloramine T). Vitamin C (ascorbic acid) was used as a known protein oxidation inhibitor.

In general, chloramine T causes the oxidation of albumin, which manifests as an increase in the fluorescence of dityrosine, kynurenine, *N*-formylkynurenine, and AGE and the content of AOPP. Extracts of fruit teas cause a decrease in albumin glycooxidation in vitro (↓fluorescence of oxidative-modified amino acids, AGE and AOPP; ↑tryptophan content). However, statistically significant differences are observed mainly at the longest time and temperature of brewing. The best anti-glycooxidative properties are shown by a lemon balm with pear infusion (Table 7).

Table 7. The effect of selected fruit tea extracts on protein glycooxidation in the model of bovine serum albumin (BSA) oxidized with chloramine T. AGE—advanced glycation end products; AOPP—advanced oxidation protein products; BSA—bovine serum albumin. * $p < 0.05$ vs. control (BSA + chloramine T, 30 min oxidation); # $p < 0.05$ vs. control (BSA + chloramine T, 60 min oxidation).

	BSA		Chloramine T		Chloramine T + Vitamin c		Chloramine T + Lemon Balm with Pear		Chloramine T + Forest Fruits		Chloramine T + Cranberry with Pomegranate		Chloramine T + Raspberry		Chloramine T + Raspberry with Linden	
	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation	30 min oxidation	60 min oxidation
Dityrosine (% of control)																
3 min 70 °C	42 * ± 2.7	40 # ± 3.3	100	100	65 * ± 2.4	76 # ± 7.1	95 ± 6.2	94 ± 3.3	100 ± 1.2	90 ± 6.6	94 ± 6.5	91 ± 5.4	93 ± 6.5	93 ± 5.9	88 ± 5.7	98 ± 0.86
3 min 100 °C							97 ± 2.4	96 ± 0.78	95 ± 6.5	93 ± 4.7	104 ± 8.0	92 ± 2.7	90 ± 4.5	94 ± 5.1	91 ± 12	89 ± 5.0
5 min 70 °C							81 * ± 2.8	92 ± 1.0	91 ± 3.5	95 ± 6.6	93 ± 12	94 ± 0.88	88 ± 3.5	95 ± 4.1	83 * ± 9.4	92 ± 3.5
5 min 100 °C							86 * ± 4.1	87 # ± 2.7	89 ± 2.9	88 # ± 3.6	90 ± 6.9	92 ± 6.2	87 ± 4.0	91 ± 1.8	90 ± 8.7	92 ± 2.2
10 min 70 °C							82 * ± 1.7	91 ± 7.3	87 ± 7.0	89 ± 3.5	88 ± 11	90 ± 5.6	85 ± 9.0	93 ± 4.2	85 ± 3.1	90 ± 5.1
10 min 100 °C							85 * ± 3.9	83 # ± 2.4	84 * ± 3.2	86 # ± 7.0	88 * ± 3.7	88 ± 0.88	85 * ± 7.3	86 # ± 5.5	84 * ± 1.1	84 # ± 5.0
Kynurenine (% of control)																
3 min 70 °C	53 * ± 3.0	36 # ± 3.6	100	100	71 * ± 4.9	88 # ± 0.96	92 ± 6.3	100 ± 3.4	95 ± 2.5	90 ± 5.3	95 ± 2.9	99 ± 6.8	93 ± 3.1	95 ± 10	99 ± 2.4	102 ± 2.3
3 min 100 °C							95 ± 4.4	101 ± 1.7	90 ± 11	92 ± 4.2	95 ± 7.4	101 ± 6.7	97 ± 2.7	94 ± 4.4	102 ± 16	90 ± 7.8
5 min 70 °C							95 ± 12	107 ± 5.4	90 ± 3.1	97 ± 2.4	93 ± 4.3	106 ± 3.9	92 ± 3.6	102 ± 3.8	93 ± 3.9	93 ± 0.83
5 min 100 °C							93 ± 5.3	86 # ± 0.89	94 ± 11	104 ± 3.6	94 ± 2.4	100 ± 1.3	87 ± 6.5	94 ± 2.6	92 ± 7.5	92 # ± 2.0
10 min 70 °C							80 * ± 1.8	102 ± 0.78	84 * ± 1.5	93 ± 6.2	88 * ± 0.79	100 ± 3.7	84 * ± 1.1	96 ± 7.9	95 ± 0.66	92 ± 0.16
10 min 100 °C							80 * ± 4.8	84 # ± 1.0	84 * ± 4.2	98 ± 1.1	76 * ± 5.4	100 ± 1.2	85 * ± 3.3	99 ± 8.7	86 ± 2.7	88 # ± 0.87
N-formylkynurenine (% of control)																
3 min 70 °C	47 * ± 4.5	42 # ± 3.3	100	100	64 * ± 1.7	64 # ± 1.7	92 * ± 0.7	80 # ± 2.1	96 ± 2.6	99 ± 3.7	97 ± 1.7	96 ± 0.58	93 * ± 3.5	98 ± 0.9	100 ± 0.56	105 ± 5.3
3 min 100 °C							84 * ± 7.8	105 ± 8.5	95 ± 1.1	89 ± 2.4	98 ± 6.2	99 ± 0.99	93 ± 3.8	90 ± 3.8	102 ± 2.9	101 ± 6.7
5 min 70 °C							101 ± 1.9	102 ± 11	93 ± 4.0	93 ± 2.8	93 ± 4.2	99 ± 1.1	91 * ± 1.8	90 ± 10	102 ± 1.4	99 ± 2.5
5 min 100 °C							92 ± 2.8	104 ± 2.4	99 ± 19	94 ± 4.5	91 ± 4.3	92 ± 0.16	90 ± 4.2	90 ± 7.3	98 ± 1.4	98 ± 5.6
10 min 70 °C							82 * ± 1.3	100 ± 3.6	91 * ± 2.7	89 # ± 1.3	86 * ± 2.3	91 ± 0.96	81 * ± 0.98	91 ± 7.4	85 * ± 4.7	91 ± 2.3
10 min 100 °C							100 ± 3.8	90 # ± 0.28	93 ± 6.4	89 # ± 0.73	94 ± 7.6	92 # ± 1.7	88 ± 2.2	82 # ± 3.5	93 ± 3.4	87 # ± 1.8

Table 7. *Cont.*

	BSA		Chloramine T		Chloramine T + Vitamin c		Chloramine T + Lemon Balm with Pear		Chloramine T + Forest Fruits		Chloramine T + Cranberry with Pomegranate		Chloramine T + Raspberry		Chloramine T + Raspberry with Linden	
	30 min oxidation	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**	**30 min oxidation**	**60 min oxidation**
	Tryptophan (% of control)															
3 min 70 °C	160 * ± 4.9	174 ± 7.1	100	100	148 * ± 6.9	131 ± 2.2	100 ± 7.8	86 ± 7.1	91 ± 6.1	76 ± 7.8	98 ± 3.6	83 ± 7.6	94 ± 11	76 ± 3.8	106 ± 4.9	84 ± 12
3 min 100 °C							81 ± 5.6	75 ± 8.7	99 ± 7.3	83 ± 7.4	102 ± 5.8	87 ± 2.2	91 ± 19	80 ± 3.9	97 ± 4.6	81 ± 10
5 min 70 °C							98 ± 9.2	84 ± 9.4	107 ± 5.5	86 ± 8.7	91 ± 14	86 ± 3.9	98 ± 4.9	95 ± 3.4	99 ± 3.4	95 ± 4.3
5 min 100 °C							103 ± 4.5	86 ± 3.5	100 ± 4.4	96 ± 1.6	108 ± 2.2	84 ± 7.1	105 ± 2.2	90 ± 2.1	103 ± 5.9	87 ± 7.8
10 min 70 °C							97 ± 5.1	103 ± 7.9	104 ± 11	94 ± 11	101 ± 21	94 ± 9	108 ± 4.7	97 ± 12	106 ± 3.3	87 ± 6.6
10 min 100 °C							116 ± 5.8 *	107 ± 9.2	111* ± 5.6	88 ± 7.2	107 ± 4.6	95 ± 8.5	105 ± 4.9	100 ± 7.0	109 ± 7.2	93 ± 22
	AGE (% of control)															
3 min 70 °C	54 * ± 2.0	45 # ± 0.56	100	100	73 * ± 0.93	81 # ± 6.7	91 ± 2.9 *	82 # ± 2.5	98 ± 0.99	93 ± 2.7	92 ± 4.0	90 # ± 1.4	103 ± 2.5	85 # ± 4.4	94 ± 6.0	96 ± 0.17
3 min 100 °C							85 ±2.3 *	85 # ± 12	94 ± 3.9	100 ± 4.5	104 ± 3.9	93 ± 1.5	103 ± 1.1	99 ± 3.7	83 * ± 6.2	94 ± 0.81
5 min 70 °C							82 ± 12 *	92 ± 2.4	89 ± 3.3	96 ± 4.4	91 ± 8.5	94 ± 6.1	89 ± 1.3	93 ± 6.6	98 ± 3.4	91 ± 3.8
5 min 100 °C							82 ± 3.1 *	86 # ± 4.1	88 ± 1.9	90 # ± 4.9	91 ± 2.1	84 # ± 1.7	84 * ± 3.8	87 # ± 3.0	84 * ± 12	90 # ± 1.4
10 min 70 °C							81 ± 0.35 *	85 # ± 6.3	87 * ± 3.5	89 ± 3.1	86 * ± 3.7	87 # ± 1.9	83 * ± 5.3	93 ± 1.8	83 * ± 3.3	87 # ± 7.3
10 min 100 °C							81 ± 0.52 *	78 # ± 3.3	86 * ± 0.62	90 # ± 2.1	81 * ± 1.8	87 # ± 1.8	77 * ± 4.7	83 # ± 1.0	80 * ± 0.81	88 # ± 5.1
	AOPP (% of control)															
3 min 70 °C	43 * ± 0.72	41 # ± 3.6	100	100	61 * ± 4.9	75 # ± 0.41	87 ± 7.1 *	91 # ± 4.2	95 ± 1.4	93 ± 1.5	95 ± 2.8	92 # ± 5.0	96 ± 0.9	94 ± 1.5	97 ± 1.4	100 ± 1.1
3 min 100 °C							81 ± 4.6 *	93 ± 0.43	92 ± 4.1	93 ± 0.9	105 ± 5.1	88 # ± 7.0	92 ± 2.4	90 # ± 1.3	100 ± 2.4	92 ± 1.5
5 min 70 °C							90 ± 0.6 *	84 # ± 1.2	94 ± 1.0	95 ± 0.56	91 * ± 1.1	92 # ± 1.8	91 * ± 4.2	93 # ± 3.6	91 * ± 3.7	95 ± 3.2
5 min 100 °C							88 ± 4.9	84 # ± 0.48	87 ± 5.3	91 # ± 4.0	95 ± 11	87 # ± 3.8	91 ± 3.5	89 # ± 2.2	91 ± 9.1	93 # ± 0.47
10 min 70 °C							82 ± 2.0 *	85 # ± 4.5	88 ± 3.1	91 ± 5.4	90 ± 12	89 # ± 3.6	83 * ± 4.5	91 ± 2.6	86 ± 3.1	94 ± 2.6
10 min 100 °C							78 ± 4.2 *	76 # ± 1.0	79* ± 3.5	80# ± 4.4	84 * ± 1.8	83 # ± 4.8	82 * ± 5.6	82 # ± 4.7	85 ± 2.2 *	89 ± 11

4. Discussion

The tea industry has been developing rapidly over the last two decades. More and more interest in a healthy lifestyle as well as the discovery of beneficial properties of teas have contributed to increased consumption of these beverages [2,25,38]. Indeed, teas are classified as functional food, i.e., products with documented health-promoting effect [39]. Although fruit teas are very popular, still little is known about their beneficial effects on the human body.

The antioxidant properties of fruit teas depend on the type and quality of the ingredients used in the process of tea production, location of the crops, and manner of the raw material processing. Interestingly, technological processes used in the production of fruit teas as well as conditions of raw material storage significantly affect the quality and health-promoting properties of teas [17,25,28,29]. Numerous studies have demonstrated that during the drying procedures (due to intensive aeration), plant raw material loses even 50% of its initial antioxidant capacity [17,40]. The raw material containing volatile substances (e.g., essential oils) and vitamins (mainly vitamin C) are particularly sensitive to processing [18,40]. Therefore, comparing antioxidant potential of fruit teas from different manufacturers (i.e., produced under different conditions) is of little and questionable value.

Tea brewing conditions (e.g., temperature and time of brewing) also significantly influence the quality of the infusion. Extraction is the simplest method of obtaining individual plant substances from a mixture of solids or liquids. Extracted compounds pass to a properly selected solvent that determines the value of the partition coefficient [40,41]. In case of fruit teas, the only solvent used is water. Therefore, to increase the efficiency of extraction, the temperature of water is raised and/or the brewing time is prolonged. However, a large part of biologically active compounds (mainly polyphenols) contained in fruit teas is susceptible to oxidation, thus high temperature and alkaline environment may be responsible for their degradation [18,40,41]. Consequently, suitable conditions of raw material extraction are crucial for the quality of the obtained infusion [23,41]. Our study is the first to compare the effect of the brewing temperature and time on the antioxidant properties of fruit teas produced and stored under the same conditions.

Based on literature analysis, we chose the most frequently used brewing times (3, 5, and 10 min) and temperatures (70 °C and 100 °C) [16,17,25,26,29]. We demonstrated that infusions with the longest brewing time have the highest antiradical activity.

A number of parameters are used to assess antioxidant properties, starting from the evaluation of individual antioxidants. However, much more information is provided by the resultant free radical scavenging capacity of a given sample, taking into account the synergistic effect of interactions between antioxidants [30,42]. In order to obtain a reliable picture of the antioxidant activity (considering the strengths and weaknesses of a given method and its applicability), it is recommended to apply at least two different methods [30,42]. In our study we evaluated TAC, DPPH, and FRAP. Although individual infusions were characterized by varied antiradical activity, the highest values of TAC, DPPH, and FRAP were observed for the longest time (10 min) and the highest temperature (100 °C) of brewing.

According to the manufacturer's recommendations, the average brewing time for dried tea should be between 3 and 5 min. Our research revealed, however, that this time is not sufficient to obtain an infusion with maximum antioxidant potential. Therefore, we recommend extending the brewing time to ~10 min. Longer extraction time enables more antioxidants to pass to the infusion, which results in better health-promoting properties (an increase in TAC, DPPH, and FRAP and a decrease in TOS).

The content of TAC, DPPH, and FRAP correlated positively with total phenolic content (TPC). Thus, increased antioxidant activity of infusions may result from high level of polyphenolic compounds. Indeed, it is believed that polyphenols are the main source of antioxidants in fruit teas. These include flavonoids, tannins, phenolic acids, stilbenoids, lignans, and others [18,40,43]. They present not only antiradical, but also anti-inflammatory or even anticancer effects [18,38]. Therefore, it is not surprising that polyphenols are used in the treatment of some systemic diseases [18,44]. The usage of polyphenols is also indicated in prevention of civilization diseases [18,44]. It is suggested that the health-promoting effects of fruit teas depend on the total phenolic content [44]. Although the scope of

TPC in the analyzed infusions is quite wide, it coincides with the data available in literature [3,16,27]. However, the comparison of the obtained results is hindered by the fact that different solvents (water, ethanol, and methanol) were used in the various studies available in literature and the manner of presenting the results is also varied (gallic acid/catechin equivalents or TPC expressed in dry sample mass/solution volume). In our study, the only applied solvent was water, as it is used to prepare the extract by the consumer.

Although we did not directly evaluate the degree of oxidation/degradation of polyphenolic compounds, TPC was highest in teas with the longest brewing time (10 min) and the highest brewing temperature (100 °C). Therefore, it can be assumed that neither an increase in extraction time nor higher temperature of water cause degradation of polyphenols in the analyzed teas. However, it cannot be excluded that polyphenols may undergo partial oxidation during the brewing process. Interestingly, partially oxidized polyphenols are characterized by a boosted ability to bind free radicals compared to their non-oxidized precursors. These changes were observed, inter alia, in catechin subjected to enzymatic oxidation [18,40,45,46]. Indeed, the improved antiradical properties of partially oxidized polyphenols can be explained by an increased ability to release hydrogen atoms of the hydroxyl group at the aromatic ring. Moreover, they may result from keeping the unpaired electrons in the aromatic ring by relocating them in the π coating [18,40,45,46].

In addition to ionizing/ultraviolet radiation and xenobiotics, high temperature is one of the most important boosters of free radicals [4,5]. For that reason, in our study we evaluated the total oxidant status (TOS) determining the total oxidant content of the analyzed sample. This parameter is particularly useful for assessing the oxidation/degradation rate of food ingredients [33]. We observed the highest TOS values at the highest brewing temperature and the shortest brewing time, while the lowest TOS values were noted at 100 °C after 10 min of brewing. It is therefore very likely that the total oxidant status decreases under the influence of antioxidants passing to infusions during the extraction process. Our hypothesis was confirmed by the negative correlation between TOS concentration and the analyzed antioxidant parameters (TAC, DPPH, and FRAP).

There are no available studies comparing the antioxidant properties of fruit tea infusions depending on the brewing temperature and time. With respect to black and green teas, it has been demonstrated that TPC is significantly higher in teas brewed in hot water, as confirmed by the results of our study [29]. On the other hand, Shannon E. et al. [27] proved that the optimum brewing time for black, green, white, and chamomile teas as well as for the blend of berry and hibiscus tea is 5 min. Extending the brewing time to 10 min did not increase the antioxidant properties [27]. Therefore, it is probable that the antiradical activity of an infusion is largely dependent on the qualitative composition of the blend (black/herbal/fruit tea).

The composition of fruit teas is not limited to one raw ingredient. The presence of particular ingredients in tea blends is determined, on the one hand, by the price of the raw material, and on the other hand, by the sensory properties responsible for the flavor, aroma, and color of the obtained infusions [2,27]. The most common ingredients of fruit teas are hibiscus flower and fruits of chokeberry, black currant, rosehip, and raspberry [47]. Although they mainly determine the color and taste of the infusions, these raw materials are a rich source of both organic acids (citric, malic, tartaric, and oxalic) and also anthocyanins and polyphenolic compounds such as protocatechuic acid [48,49]. Therefore, they may be responsible for the antioxidant properties of fruit teas. However, despite numerous studies on the antioxidant properties of green, black, and red teas, still little is known about teas made from dried fruit. Pękal et al. [3] have shown that the antioxidant activity of studied teas increases in the following order; fruit tea, flavored black tea, and premium black tea. Indeed, the antioxidant properties of a particular infusion are strongly influenced by the percentage of individual raw materials in the mass of the entire product, which translates into a different content of biologically active compounds. In our study, the highest antioxidant activity (highest TAC, DPPH, and TPC) was found in the mixture of lemon balm and pear. In this product, 50% of the dry matter is constituted by the lemon balm herb, which is basically an oil-bearing raw material. However, apart from the essential oil, this raw material also has other biologically active compounds, mainly phenolic acids: rosemarinic, caffeic, chlorogenic, and ferulic acids, which are both esters and glycosides. This raw material also contains triterpenic acids, flavonoids, and minerals [50]. On the other hand, pear fruit has a high content of vitamin C, anthocyanins, and other antioxidants, which may affect health-promoting properties of the tea made from this material [51,52]. Indeed, it is believed that the main source of antioxidants are fruits, among which berries are particularly rich in anthocyanins and tannins [53]. Unfortunately, the available literature lacks data on the total antioxidant potential of the raw material. In our study, infusions of forest fruits, cranberry with pomegranate, raspberry and raspberry with linden also showed high antioxidant activity. Indeed, many studies have shown that these raw materials are rich sources of flavonoids (mainly quercetin, kaempferol, and acacetin derivatives) as well as essential oil [16,53–55]. Interestingly, linden, apart from flavonoids (rutin, hyperoside, quercetin, astragalin, and thiroside) and essential oil, also contains mucous compounds, amino acids or tocopherol, which also determines antioxidant properties [56,57]. The addition of these ingredients may intensify the antiradical effect in comparison to tea with rasberry alone. Sahin et al. [16] demonstrated that pomegranate fruit has the highest antioxidant capacity among the evaluated fruit teas. In our study, the cranberry with pomegranate tea also reached high values of TAC, DPPH, FRAP, and TPC, while the cranberry infusion was already characterized by low antioxidant activity. It can therefore be assumed that it is the pomegranate fruit that is responsible for the health benefits of the cranberry-pomegranate tea. Sahin et al. [16] also showed a significant antioxidant capacity of berry teas (blueberry and blackberry), which was also covered by our study. We showed that forest fruit tea is one of the five teas with the best antioxidant properties.

An important part of our study was also the assessment of the effect of fruit tea extracts on the glycoxidative properties of albumin. Albumin is one of the best-known proteins of the human body involved in the maintenance of oncotic pressure, regulation of the acid–base and oxidative–antioxidative balance as well as transport of many endogenous and exogenous substances [58]. The most sensitive to oxidation are alkaline, aromatic, and sulfur-containing amino acids [59]. In the present study, we evaluated the effect of extracts with the best antioxidant properties on albumin glycooxidation in vitro. We have shown that the analyzed fruit teas reduce oxidation and glycation of albumin observed as a decrease in fluorescence of aromatic amino acids (dityrosine, kynurenine, and *N*-formylkynurenine), reduced AGE and AOPP levels as well as an increase in tryptophan content. However, the ability to counteract glycation and protein oxidation has been demonstrated mainly in tea extracts with the longest extraction time and the highest temperature. This confirms our previous results on the relationship between antioxidant properties and brewing temperature/time. It is well known that the products of protein oxidation and glycation interact with other proteins, disturbing their structure and function. AGE and AOPP bind to specific receptors and activate many signaling pathways (e.g., NF-κB, NJK, and p21 RAS) that intensify the secretion of proinflammatory cytokines and pro-thrombotic factors [60,61]. AGE and AOPP can also accumulate in tissues, which disrupts the functioning of many organs [60,61]. Thus, fruit tea could improve the redox balance in the course of diseases with a proven etiology of oxidative stress. They can also be used to prevent cancer, inflammation, neurodegenerative diseases, or metabolic diseases, where increased protein glycooxidation occurs. Therefore, our study is a starting point for further research on the therapy of reducing protein oxidation/glycation in living systems.

In conclusion, we proved that brewing time has a significant impact on the antioxidant properties of fruit teas. This may be related to a better release of the biologically active substances contained in the dried fruit and their easier transfer to the infusion at a longer extraction time (10 min). Although fruit teas are a rich source of numerous natural antioxidants, it should be remembered that their proper preparation is crucial. Further studies should aim at developing the optimum qualitative–quantitative composition of teas in order to obtain maximum antioxidant properties at acceptable sensory qualities. The evaluation of antioxidant properties of fruit teas may contribute to the consumer's conscious choice of the final product which, apart from its flavor, will offer valuable health-promoting properties. It is also necessary to assess the effect of fruit tea extracts on antioxidant properties in vivo.

Our study also had certain limitations. First of all, we did not assess individual phytochemicals separately, so we do not know which compounds are responsible for the observed antioxidant properties. Moreover, the extraction of dried fruit was performed in only one solvent, which is also a limitation of our work. As teas with the best antioxidant effect are produced by berries, it is possible that phytochemicals such as anthocyanins have the most antiradical activity. Therefore, obtaining a phytochemical/antioxidant profile of the raw material should be the next step in research. Interestingly, Atoui et al. [62] identified over 60 different flavonoids, phenolic acids and their derivatives in leaf tea and herbal infusions.

5. Conclusions

Fruit teas are a valuable dietary supplement providing natural antioxidants. The antioxidant properties of fruit teas depend mainly on the brewing time, therefore a longer extraction time (10 min) should be implemented during their preparation. Fruit teas owe their high antioxidant activity to the presence of polyphenolic compounds in the infusion. The best antioxidant properties are found in the teas: lemon balm with pear, forest fruits, cranberry with pomegranate, raspberry, and raspberry with linden. Extracts from fruit teas also diminish the oxidation and glycation of albumin in vitro. Health-promoting properties of fruit teas can be modified by changing the qualitative and quantitative composition of the ingredients.

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