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Effects of different polyphenol-rich herbal teas on reducing predicted glycemic index

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Abstract

The purpose of this study was to investigate the effects of different polyphenol-rich herbal teas on reducing the *in vitro* starch digestibility of white bread and evaluation of predicted glycemic indexes. Generally, except for the goji berry treatment, all herbal teas reduced the starch digestibility and predicted glycemic index of white bread. Compared to untreated white bread, the rapidly digestible starch levels were decreased by 10% and 12% in the turmeric tea treatment. In addition, hydrolysis indexes were decreased by 12% and 10% in the black tea treatment compared to untreated white bread. The turmeric treatment on white bread reduced the predicted glycemic index more than other teas. It is thought that the curcumin in turmeric has more inhibitory effects on α-amylase activity than other teas. We also demonstrated that dietary polyphenols such as anthocyanins and catechins found in herbal teas might reduce starch digestion by inhibiting α-amylase and α-glucosidase thereby lowering the glycemic index of foods.

Keywords: polyphenols; herbal teas; starch digestion; glycemic index; nutrition; *in vivo*.

Practical Application: When we evaluate the effects of polyphenol-rich herbal teas treatment on the quality of starch fractions, overall, the black tea, cinnamon, goji berry, blueberry, cranberry, and rosehip were increased the starch fractions quality. We revealed that dietary polyphenols such as anthocyanins and catechins found in herbal teas could reduce the starch digestion by the inhibition of α-amylase and α- glucosidase resulting in lowering of the GI of foodstuffs. Overall, consumption of the herbal teas made of colored berries, turmeric, and cinnamon may contribute to lowering the glycemic index of foods.

1 Introduction

Consuming high glycemic index (GI) foods is associated with weight gain, insulin resistance, increased blood glucose levels, obesity, cardiovascular disease, retinopathy, nephropathy, and neuropathy (Chiu & Taylor, 2011). The GI values of foods are important data for the sustainability of healthy nutrition as well as control of diabetes. The GI classifies carbohydrate-containing foods according to their glycemic effect or increase in blood sugar after food consumption in individuals (Brand-Miller et al., 2009; Wiemer, 2018) as ≤55 is low, 56-69 is medium, and 70≤ is high (Food and Agriculture Organization, 1998). According to the global estimates of diabetes prevalence studies, the estimated number of people with diabetes is 537 million worldwide and it is expected to increase to 643 million by 2030 and 783 million by 2045 (International Diabetes Federation, 2021).

The GI of a food is influenced by factors such as botanical sources, food processing, free sugar content, starch fractions, starch-protein and starch-lipid interactions, and content of polyphenols (Yaman et al, 2019; Thondre, 2013). Recent epidemiological studies suggest that dietary polyphenols could be used for the prevention and treatment of type 2 diabetes and insulin resistance due to their anti-diabetic properties. Polyphenols are a heterogeneous phytochemical group containing phenol rings. Plant-based and fruit-based foods such as broccoli, onion, grapes, pears, apples, and cherries are the main sources of polyphenols. According to their chemical structure, polyphenols are divided into four groups: flavonoids, phenolic acids, stilbenes, and lignans. Flavones, flavonols, flavanones, isoflavones, and anthocyanins are in the flavonoids group while chlorogenic acid and ferulic acid are in the phenolic acid group (Kim et al., 2016). Consumption of phenolic compounds increases the activation of the 5' adenosine monophosphate-activated protein kinase (AMPK). AMPK enhances the translocation of the glucose transporter (GLUT4) and provides insulin-independent cellular glucose uptake in the skeletal muscle and liver in individuals with type 2 diabetes (Kismiroğlu et al., 2020). Kobayashi et al. (2000) reported that green tea polyphenols such as epigallochatechin gallate (EGCG)–epichatechin gallate (ECG) reduce glucose uptake by inhibiting the Na^+-dependent glucose transporter (SGLT) in intestinal enterocytes. The starch is composed of amylose and amylopectin and is broken down into maltose, maltotriose, and α-dextrins by α-amylase and α-glucosidase. Limited studies demonstrate that dietary polyphenols such as anthocyanins and catechins could reduce starch digestion by the inhibition of α-amylase and α-glucosidase (Hanhineva et al., 2010). Studies show that rapidly digestible starch and the free sugar content of a food are directly related to an increase in the GI of that food (Englyst et al.,1996; Odenigbo et al., 2012).

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The Food and Agriculture Organization (1998) and International Organization for Standardization (2008) has standardized the analysis of GI values of foods using *in vivo* methods. FAO/WHO 1998 has now been extended to the international standard "ISO 26642:2010 specifies a method for the determination of the glycemic index (GI) of carbohydrates in foods". However, *in vivo* human or animal studies have time-consuming, cost, and ethical difficulties. Hence, alternatively, *in vitro* methods have been used extensively for the determination of the GI of foods (Çatak, 2019; Kamstrup et al., 2017). The basis of the *in vitro* GI method is to compare the starch digestibility of the test sample with white bread in a specified time. The GI of the foods is determined using the hydrolysis index (HI) value in the formula developed by Goñi et al. (1996).

In many studies, the GI of foods is determined using *in vitro* methods. Some studies show the starch hydrolysis rate may also decrease in the presence of phenolic compounds in a food. The purpose of this study was to investigate the effects of different polyphenol-rich herbal teas on reducing the *in vitro* starch digestibility of white bread, on the quality of starch fractions, and to evaluate the *in vitro* GI.

2 Materials and methods

2.1 Materials

Methanol, ethanol, potassium hydroxide (KOH), sodium acetate, pepsin (from porcine gastric mucosa, 250 U/mL), pancreatin (from porcine pancreas, 8 × USP specifications), and guar gum were obtained from Sigma-Aldrich Co., LLC. (St. Louis, MO, USA). Invertase (from yeast, 300 U/mL), thermostable α-amylase (from *Bacillus licheniformis,* 3000 U/mL), amyloglucosidase (from *Aspergillus niger*, 3330 U/mL), and glucose oxidase-peroxidase (GOPOD) regent were purchased from Megazyme (Wicklow, Ireland).

2.2 Sampling

In this study, ten different polyphenol-rich herbal teas consumed in Turkey were obtained from different spice shops in Istanbul, Turkey (Table 1).

Table 1. Effects of different herbal teas on *in vitro* starch digestibility and starch fractions.

Tea treatment	RDS g/100 g	SDS g/100 g	RS g/100 g
Green Tea	21.2 ± 0.3^{a}	24.7 ± 0.1^{bc}	10.7 ± 0.1^{e}
Turmeric	17.6 ± 0.2^{f}	20.9 ± 0.1^{g}	18.3 ± 0.3^{a}
Ginger	18.5 ± 0.3^{cde}	26.4 ± 0.2^{a}	11.8 ± 0.3^{d}
Black Tea	17.2 ± 0.2^{f}	24.0 ± 0.2^{d}	15.4 ± 0.3^{b}
Cinnamon	18.2 ± 0.2^{e}	24.5 ± 0.3^{c}	14.0 ± 0.5^{c}
Goji berry	18.9 ± 0.2^{bcd}	23.7 ± 0.2^{de}	14.1 ± 0.1^{c}
Elderberry	18.4 ± 0.2^{cde}	26.3 ± 0.1^{a}	11.9 ± 0.4^{d}
Blueberry	18.7 ± 0.1^{cde}	22.8 ± 0.2^{f}	15.1 ± 0.6^{b}
Rosehip	18.3 ± 0.2^{de}	23.8 ± 0.1^{d}	14.6 ± 0.1^{bc}
Cranberry	19.0 ± 0.3^{bc}	23.3 ± 0.2^{e}	14.4 ± 0.4^{bc}
White Bread	19.5 ± 0.2^{b}	25.1 ± 0.2^{b}	12.1 ± 0.4^{d}

Values refer to the mean ± standard deviation (n = 3). The different letters in the same column indicate that there are statistical differences between the applications (ANOVA, $p < 0.05$, Tukey's test).

2.3 Starch analysis

The starch amount of white bread was determined by the Goñi et al. (1996) method with some modifications. First, 0.1 g white bread was weighed into a 50 mL falcon tube and treated with 0.2 mL aqueous ethanol (80%, v/v) to ensure dispersion. Then, 2 mL KOH (2 M) solution was added and mixed with a magnetic bar (5 × 15 mm) for 10 min in an ice/water bath. After that, 8 mL sodium acetate (1 M) solution (pH 3.8) was added. Thermostable α-amylase and amyloglucosidase (0.1 mL) enzymes were added to initiate starch hydrolysis. The reaction was conducted at 50 °C for 30 min. The final volume of the hydrolyzed solution was completed with deionized water and centrifuged at 8000 x *g*, for 5 min. After this stage, 0.1 mL centrifuged liquid sample was treated with 3.0 mL GOPOD solution in a 10 mL glass tube in a water bath at 50 °C for 30 min. The absorbance of the sample at 510 nm was measured using the UV spectrophotometer (UV-1280, Shimadzu).

2.4 In vitro starch digestibility and predicted glycemic index

In vitro starch digestibility of the white bread treated with polyphenol-rich herbal teas was measured using the method of Englyst et al. (1992) with some modifications. Gastric and intestinal enzymes for digestion were prepared as follows.

Enzyme Solution 1 (Pepsin/Guar Gum Solution): 0.5 g pepsin and 0.5 g guar gum were dissolved in a 100 mL volumetric flask with 0.05 N HCl solution. The final volume was completed with 0.05 N HCl.

Enzyme Solution 2 (pancreatin (136 mg/mL), amyloglucosidase (13.4 U/mL), and invertase (25.43 U/mL) for one sample): For one sample, 680 mg pancreatin was dissolved in a 50 mL falcon tube with 4 ml deionized water. Then, it was centrifuged at 3000 rpm for 10 min and the residue was discarded. After that, 67 U amyloglucosidase and 127.15 U invertase were added to the centrifuged pancreatin liquid sample and the volume was completed to 5 mL with deionized water.

In vitro starch digestibility

We used herbal teas in grounded teabag form, the teabags were brewed, and 4 mL of brewed herbal tea was used for 1 g of white bread (Pekcan et al., 2016). The duration of tea brewing was 10 min, and the temperature of the water was 100 °C (Ilyasoğlu & Arpa Zemzemoğlu, 2021).

In this study, each polyphenol-rich herbal tea was treated with 1 g homogenized white bread in a 250 mL Erlenmeyer flask. Then, the digestion was started with the addition of 5 mL deionized water and 10 mL Enzyme Solution 1. The mixture was incubated at 37 °C in a shaking water bath (175 strokes/min) for 30 min for protein hydrolysis. Next, 5.0 mL sodium acetate solution (0.5 M) was added and the pH was adjusted to 5.2. After this stage, Enzyme Solution 2 (5 mL) was added and the volume was completed to 50 mL with deionized water and incubated at 37 °C in a shaking water bath. During the incubation, 0.5 mL of liquid sample was taken at 20, 30, 60, 90, and 120 min and transferred into a 10 mL glass tube. The solution was held for 5 min in a boiling water bath to complete denaturation of the

digestive enzymes. The liquid sample was transferred into a 15 mL falcon tube and the volume was completed to 5 mL followed by centrifuged at 8000 x *g* for 10 min. Finally, the glucose content was measured as in the starch determination.

The starch fractions were determined as follows:

RDS: rapidly digestible starch is defined as the starch digested in 20 min

SDS: slowly digestible starch is defined as the starch digested in between 20 and 120 min

RS: resistant starch RS = TS – (RDS + SDS)

TS: total starch, TS = TG x 0.9

TG: Total glucose

The predicted glycemic index (pGI) was calculated from the HI values of each sample. HI was determined by dividing the area under the hydrolysis curve for WB treated with each tea by the area obtained for WB. The pGI was calculated using the formula described by Goñi et al. (1996): pGI = 39.21 + 0.803HI.

2.5 Statistical analysis

All analyses were performed three times, and the mean value was used. Significant differences between the applications were statistically evaluated using one-way analysis of variance (ANOVA; $p < 0.05$, Tukey's test). GraphPad Prism software (San Diego, CA, USA) was used to determine significant differences between groups by ANOVA. When a significant ($p < .05$) main effect was found, mean values were further analyzed using Tukey's Multiple Range Test comparison.

3 Results and discussion

3.1 Starch fractions

In this study, the effects of polyphenol-rich herbal teas on the amount of RDS, SDS, and RS in white bread (WB) were investigated. The amount of RDS, SDS, and RS are shown in Table 1 and ranged from 17.6 to 21.2 g/100 g, from 20.9 to 26.4 g/100 g, and from 10.7 to 18.3 g/100 g in WB treated with different herbal teas, respectively. The starch value of white bread is 56.7 ± 0.3 g/100 g. RDS is defined as the starch digested in 20 min. The lowest amount of RDS was detected in WB treated with turmeric while the highest amount was detected in WB treated with green tea. Lower amounts of RDS were also detected in the WB treated with ginger, cinnamon, elderberry, blueberry, and rosehip compared with non-treated WB. However, there was no difference between the goji berry and cranberry treated and non-treated WB. SDS is defined as the starch digested in between 20 and 120 min. The lowest amount of SDS was detected in WB treated with turmeric while the highest amount was detected in WB treated with ginger and elderberry compared with non-treated WB. Lower amounts of SDS were detected in the WB treated with black tea, cinnamon, goji berry, cranberry, and rosehip compared with non-treated WB. However, there was no statistical difference between the WB treated with green tea and non-treated WB in the amount of SDS. RS is defined as the difference between the total starch and the amount of starch digested within 120 min. The highest amount of RS was detected in WB treated with turmeric while the lowest amount was detected in WB treated with green tea. Higher amounts of RS were also detected in the WB treated with black tea, cinnamon, goji berry, blueberry, cranberry, and rosehip compared with non-treated WB. However, there was no statistical difference between the WB treated with ginger and elderberry and non-treated WB in the amount of RS. When we evaluated the effects of polyphenol-rich herbal tea treatment on the quality of starch fractions, overall, the green tea, ginger, and elderberry treatments showed no effect on the starch fraction quality.

The ratio of starch digestion levels of WB treated with different herbal teas from the initial starch digestion to 120 min is shown in Table 2. The lowest starch digestion ratio was detected in the WB treated with turmeric and black tea by 31.1 and 30.5% at 20 min, respectively. On the other hand, the highest ratio at 20 min was detected in the WB treated with green tea by 37.6%. The WB treated with green tea showed the highest starch digestion (81.5%) compared with non-treated WB (79.0%) at 120 min. The lowest starch digestion was detected in the WB

Table 2. The starch digestion ratio levels from the initial time (0 min) to 120 min.

Tea treatment	20'	30'	60'	90'	120'
Green Tea	37.6 ± 0.5 ^{a}	39.0 ± 0.4 ^{bc}	47.7 ± 0.5 ^{d}	61.0 ± 0.3 ^{f}	81.5 ± 0.5 ^{a}
Turmeric	31.1 ± 0.4 ^{fg}	37.7 ± 0.2 ^{de}	48.6 ± 0.9 ^{d}	59.1 ± 0.4 ^{g}	68.1 ± 0.3 ^{f}
Ginger	32.8 ± 0.4 ^{cde}	39.2 ± 0.5 ^{bc}	53.9 ± 0.3 ^{b}	66.6 ± 0.3 ^{b}	79.6 ± 0.2 ^{b}
Black Tea	30.5 ± 0.3 ^{g}	38.5 ± 0.3 ^{cde}	48.3 ± 0.4 ^{d}	63.9 ± 0.4 ^{d}	73.1 ± 0.4 ^{e}
Cinnamon	32.2 ± 0.4 ^{ef}	38.7 ± 0.4 ^{bcd}	53.9 ± 0.3 ^{b}	67.5 ± 0.4 ^{b}	75.7 ± 0.4 ^{c}
Goji berry	33.4 ± 0.3 ^{bcd}	40.0 ± 0.4 ^{ab}	56.4 ± 0.3 ^{a}	67.4 ± 0.4 ^{b}	75.5 ± 0.3 ^{c}
Elderberry	32.7 ± 0.3 ^{cde}	37.7 ± 0.4 ^{e}	53.7 ± 0.5 ^{b}	67.1 ± 0.7 ^{b}	79.3 ± 0.8 ^{b}
Blueberry	33.2 ± 0.2 ^{cde}	39.2 ± 0.4 ^{bc}	53.4 ± 0.2 ^{bc}	62.5 ± 0.2 ^{e}	73.6 ± 0.5 ^{de}
Rosehip	32.4 ± 0.3 ^{de}	38.1 ± 0.3 ^{cde}	52.1 ± 0.3 ^{c}	62.0 ± 0.5 ^{ef}	74.6 ± 0.4 ^{cd}
Cranberry	33.6 ± 0.5 ^{bc}	39.2 ± 0.4 ^{bc}	52.8 ± 0.3 ^{bc}	70.9 ± 0.3 ^{a}	74.9 ± 0.3 ^{c}
Bread	34.6 ± 0.4 ^{b}	40.8 ± 0.3 ^{a}	57.5 ± 0.6 ^{a}	65.2 ± 0.3 ^{c}	79.0 ± 0.4 ^{b}

Values refer to the mean ± standard deviation (n = 3). The different letters in the same column indicate that there are statistical differences between the applications (ANOVA, $p < 0.05$, Tukey's test).

treated with turmeric and black tea both at 20 and 120 min (Figure 1). When we evaluated the effects of herbal teas on the WB, both turmeric and black tea showed low digestion ratios at 20 and 120 min.

Hydrolysis index and estimated glycemic index

The HI of the WB treated with herbal teas was calculated by comparing the area under the hydrolysis curve (0 to 90 min) from WB treated with herbal teas to the area of non-treated WB (reference sample). The GI of the WB treated with herbal teas was calculated using the empirical formula proposed by Goñi et al. (1996). The estimated GI of WB was 94.6 when the HI of WB was accepted as 100 in the formula. The hydrolysis curves for the WB treated with different herbal teas are shown in Figure 1.

Calculated HI and pGI values of the WB treated with different herbal teas are shown in Table 3. The HI of the WB treated with different herbal teas ranged from 88.3 (turmeric) to 99.1 (goji berry). As seen, except for the WB treated with goji berry, the WB treated with different teas showed lower HI than the non-treated WB. When we compared the effects of different herbal teas on the HI of WB, treatment with turmeric, green tea, rosehip, and black tea reduced the HI of WB more than the other teas. The pGI of the WB treated with different herbal teas ranged from 88.2 to 94.1. Turmeric and black tea treatments on WB reduced the pGI of WB more than other teas. Generally, except for the goji berry treatment, all herbal teas had the effect of reducing the pGI of WB. The estimated GI of the WB treated with the different teas was lower than that of non-treated WB (p <0.05), except for the goji berry treatment.

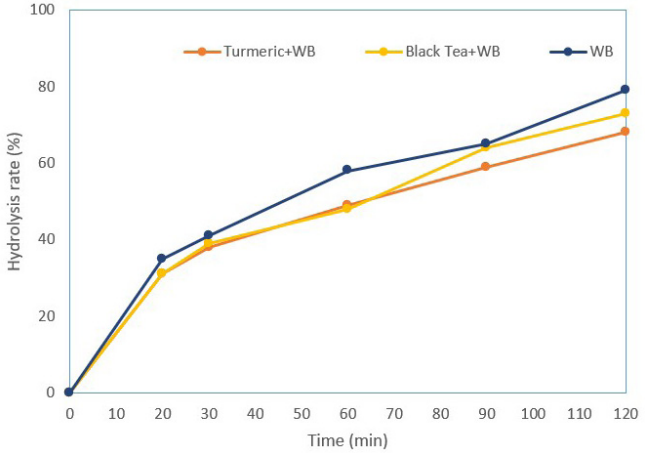

Figure 1. *In vitro* starch hydrolysis rate of white bread (WB) treated with turmeric and black tea.

Table 3. Hydrolysis index (HI) and predicted glycemic index (pGI) of WB treated with different herbal teas.

Tea treatment	HI	pGI
Green Tea	91.4 ± 0.9^{ef}	89.9 ± 0.2^{ef}
Turmeric	88.3 ± 1.2^{g}	88.2 ± 0.5^{g}
Ginger	96.4 ± 0.8^{cd}	92.7 ± 0.4^{cd}
Black Tea	90.0 ± 0.8^{fg}	89.1 ± 0.3^{fg}
Cinnamon	96.4 ± 0.8^{cd}	92.6 ± 0.4^{cd}
Goji berry	99.1 ± 0.7^{ab}	94.1 ± 0.4^{ab}
Elderberry	95.6 ± 0.8^{cd}	92.2 ± 0.3^{cd}
Blueberry	94.7 ± 0.6^{d}	91.7 ± 0.3^{d}
Rosehip	92.6 ± 0.7^{e}	90.6 ± 0.2^{e}
Cranberry	97.4 ± 0.8^{bc}	93.2 ± 0.3^{bc}
Bread	100.0 ± 0.9^{a}	94.6 ± 0.5^{a}

Values refer to the mean ± standard deviation (n = 3). The different letters in the same column indicate that there are statistical differences between the applications (ANOVA, p < 0.05, Tukey's test).

When we evaluated the association between the RDS and HI, the amount of RDS was decreased by the treatments of black tea and turmeric and the HI of white bread was also decreased. The amount of RS was increased by the treatments with black tea and turmeric while the HI of white bread was decreased. There is no statistical association between the ratio of SDS and HI of WB. Interestingly, we found a correlation between the RDS and HI in the WB treated with herbal teas except for green tea treatment. The RDS level of the WB treated with green tea was higher than that of non-treated WB. Although the green tea treatment increased the RDS level of the WB, the treatment decreased the level of HI. For instance, the levels of the RDS and HI in the turmeric and black tea treatments compared with the control were reduced by 10 and 12%, and 12 and 10%, respectively. The green tea treatment decreased both the RS level and HI of WB compared with non-treated WB. Some studies show that RDS, SDS, and RS content may decrease the GI (Hodge et al., 2004; Zhang & Hamaker, 2009) however, in our study, only the amount of RDS and RS content affected the GI.

The foods high in available carbohydrates increase postprandial hyperglycemia and hyperinsulinemia. Studies demonstrate that consuming high glycemic indexed foods induces insulin resistance, obesity, and type 2 diabetes. For this reason, it is advised to consume low glycemic indexed foods for the control of hyperglycemia (Ludwig, 2002). The starch in WB is composed of amylose and amylopectin fractions. The main enzymes that play a role in the digestion of dietary starch are α-amylase and α-glucosidase. The α-amylase is secreted by the pancreas and digests the starch into maltose, maltotriose, and α-dextrins. The final digestion of these residues is achieved with α-glucosidase and it hydrolyses the α-1,4-bound glucose residues into free glucose. The glucose is taken into the enterocytes and transferred into circulation by the vena portal (Hanhineva et al., 2010; Koh et al., 2010). The foods containing dietary polyphenols such as anthocyanins, catechins, flavanones, flavonols, flavones, and isoflavones may reduce carbohydrate digestion by inhibiting α-amylase and α-glucosidase in the small intestine. The inhibitory effects of some polyphenols from strawberries, raspberries, blackcurrants, and blueberries on the activity of α-amylase and α-glucosidase were demonstrated using *in vitro* studies. The Na^+-dependent SGLT1 glucose transporter in the enterocytes may be inhibited by some polyphenols such as chlorogenic, quercetin, and tea catechins (Hanhineva et al., 2010).

Turmeric contains curcumin and its analogs such as demethoxycurcumin and bisdemethoxycurcumin. Curcumin has anti-inflammatory, anti-cancer, and anti-diabetic properties (Aggarwal et al., 2003). The polyphenol concentration of turmeric

(57.7 µg/g) is approximately fivefold higher than that of curcumin and powdered turmeric has a higher antioxidant activity than pure curcumin (Račková et al., 2009). Najafian (2015) studied the inhibitory effects of curcumin on α-amylase activity in rats. The blood glucose and insulin levels were decreased with the administration of curcumin in both healthy and diabetic rats. It is thought in that study that less glucose was liberated from the starch by the inhibitory effects of curcumin. As seen from our study, turmeric treatment decreased both the RDS and SDS levels and HI of WB and increased the RS level compared with non-treated WB. Thus, turmeric treatment on WB induced a greater effect on the pGI of WB compared with other teas.

Berries contain high amounts of polyphenols such as pro- or anthocyanins, flavonols, and phenolic acids. Consumption of fruit containing anthocyanins reduces cardiovascular diseases and diabetic complications. In a clinical study, sucrose was orally administered with appropriate amounts of polyphenols (bilberries, blackcurrants, cranberries, and strawberries) and the plasma glucose levels were decreased compared to the control group. It is thought that the sucrose digestion enzymes were delayed by the polyphenols (Törrönen et al., 2010; Wilson et al., 2008). Colored berries contain high amounts of cyanidin-3-glucoside anthocyanin, which has important antioxidant activities (Ding et al., 2006). Elderberry contains an important amount of antioxidant flavonols and phenolic acids such as Quercetin 3-O-rutinoside, p-coumaric acid, chlorogenic, and chlorogenic acids and cyanidin derivatives (Loizzo et al., 2016). According to the literature, cranberries have higher antioxidant activity than blueberries because they contain a higher amount of anthocyanins than blueberries. In addition, the cranberry contains approximately tenfold higher Cyanidin-3-O-glucoside than the blueberry (Diaconeasa et al., 2019). As seen from the colored berries (goji berry, blueberry, cranberry, and elderberry), except for the goji berry treatment, the RDS and HI values of WB were decreased while the RS values of WB were increased compared with non-treated WB. Thus, overall, berry treatment reduced the estimated GI of WB.

When comparing the antioxidant activities between the goji berry and blueberry, the blueberry has about twofold more antioxidant activity (19.36 mmol Fe^{2+}/kg) than the goji berry. The goji berry contains some Cinnamic acids (Chlorogenic acid, Coumaric acid, and Ferulic acid) and some mono-terpenes but does not contain flavonols such as quercetin derivatives (Donno et al., 2015). Thus, the antioxidant properties of the goji berry are less than other berries. We also demonstrated in our study that treatment of WB with the goji berry did not change the HI or pGI of WB. It is thought that goji berry treatment does not affect the digestive enzymes.

In a clinical study on diabetic rats, administration of appropriate amounts of polyphenol-rich cinnamon extracts, which mainly contain procyanidin oligomers, cinnamic acid, and cinnamaldehyde, regulates blood glucose levels (Krishnakumar et al., 2014). In another clinical study, it was demonstrated that cinnamon proanthocyanidins may regulate the insulin signaling pathways and blood glucose levels (Qin et al., 2010). As seen from our study, the cinnamon treatment decreased both the RDS and SDS levels and HI of WB but increased the RS level compared with non-treated WB. Thus, cinnamon treatment of WB reduced the pGI of WB compared with non-treated WB.

Matsumoto et al. (1993) studied the effects of tea catechins on the digestion of starch and sucrose in rats. Tea catechins administered orally to rats inhibited the activity of amylase and sucrase reducing the digestion of starch and sucrose. As a result, the increase of plasma glucose levels was suppressed by tea catechins. It was also indicated that flavonols, theaflavins, and gallate esters inhibit α-amylase activity. The tea catechins such as theaflavins inhibit sucrase and maltase less than anthocyanidins (Williamson, 2013). Compared to green tea, black tea has more theaflavins. In a study on rats, it was assumed that theaflavins have more anti-hyperglycemic effects than catechins because theaflavins had more inhibitory effects on maltase (Matsui et al., 2007). We also demonstrated that when comparing the RDS, SDS, and RS values between the black tea and green tea treatments, the black tea treatment on WB showed better quality starch fractions than the green tea treatment. However, when we compared the HI values, there was no statistical difference between the WB treated with green tea and black tea.

4 Conclusion

Consuming high GI foods is associated with obesity, insulin resistance, and diabetic complications. Epidemiological studies suggest that dietary polyphenols could be used for the prevention and treatment of type 2 diabetes due to their anti-diabetic properties. In the present study, we also demonstrated that dietary polyphenols such as anthocyanins and catechins found in herbal teas could reduce starch digestion by the inhibition of α-amylase and α-glucosidase resulting in lowering the GI of foods. When we evaluated the effects of polyphenol-rich herbal tea treatment on the quality of starch fractions, overall, the black tea, cinnamon, goji berry, blueberry, cranberry, and rosehip increased the starch fraction quality. The turmeric treatment decreased both the RDS and SDS levels and HI of WB and increased the RS level compared with non-treated WB. Thus, turmeric treatment on WB has a greater effect reducing the pGI of WB compared with other teas. It is thought that curcumin in turmeric has more inhibitory effects on α-amylase activity. When we compare the RDS, SDS, and RS values between the black tea and green tea treatments, the black tea treatment on WB showed a better quality starch fraction than the green tea treatment. This may be because the black tea has a higher amount of theaflavins than green tea. Generally, except for the goji berry treatment, all herbal teas had the effect of reducing the starch digestibility and pGI of WB. Thus, consumption of herbal teas made from colored berries, turmeric, and cinnamon may contribute to reducing the GI of foods. Our study also has limitations. Though this study includes high-quality results, the study is an *in vitro* study. Therefore, the current results of the study need to be supported by *in vivo* studies.

Conflict of interest

The authors declare no conflict of interest.

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References

Aggarwal, B. B., Kumar, A., & Bharti, A. C. (2003). Anticancer potential of curcumin: preclinical and clinical studies. *Anticancer Research*, *23*(1), 363-398.

Brand-Miller, J., McMillan-Price, J., Steinbeck, K., & Caterson, I. (2009). Dietary glycemic index: health implications. *Journal of the American College of Nutrition*, 28(4, Suppl.), 446S-449S. http://dx.doi.org/10.1080/07315724.2009.10718110. PMid:20234031.

Çatak, J. (2019). Ülkemizde Tüketilen Bazı Gıda Ürünleri ile Bisküvilerin Glisemik İndekslerinin İn Vitro Yöntemlerle Belirlenmesi. *Avrupa Bilim ve Teknoloji Dergisi*, (16), 940-947.

Chiu, C. J., & Taylor, A. (2011). Dietary hyperglycemia, glycemic index and metabolic retinal diseases. *Progress in Retinal and Eye Research*, 30(1), 18-53. http://dx.doi.org/10.1016/j.preteyeres.2010.09.001. PMid:20868767.

Diaconeasa, Z., Iuhas, C. I., Ayvaz, H., Rugină, D., Stanilă, A., Dulf, F., Bunea, A., Socaci, S. A., Socaciu, C., & Pintea, A. (2019). Phytochemical characterization of commercial processed blueberry, blackberry, blackcurrant, cranberry, and raspberry and their antioxidant activity. *Antioxidants*, 8(11), 540. http://dx.doi.org/10.3390/antiox8110540. PMid:31717652.

Ding, M., Feng, R., Wang, S. Y., Bowman, L., Lu, Y., Qian, Y., Castranova, V., Jiang, B.-H., & Shi, X. (2006). Cyanidin-3-glucoside, a natural product derived from blackberry, exhibits chemopreventive and chemotherapeutic activity. *The Journal of Biological Chemistry*, 281(25), 17359-17368. http://dx.doi.org/10.1074/jbc.M600861200. PMid:16618699.

Donno, D., Beccaro, G. L., Mellano, M. G., Cerutti, A. K., & Bounous, G. (2015). Goji berry fruit (*Lycium* spp.): antioxidant compound fingerprint and bioactivity evaluation. *Journal of Functional Foods*, 18, 1070-1085. http://dx.doi.org/10.1016/j.jff.2014.05.020.

Englyst, H. N., Kingman, S. M., & Cummings, J. H. (1992). Classification and measurement of nutritionally important starch fractions. *European Journal of Clinical Nutrition*, 46(Suppl. 2), S33-S50. PMid:1330528.

Englyst, H. N., Veenstra, J., & Hudson, G. J. (1996). Measurement of rapidly available glucose (RAG) in plant foods: a potential in vitro predictor of the glycaemic response. *British Journal of Nutrition*, 75(3), 327-337. http://dx.doi.org/10.1079/BJN19960137. PMid:8785208.

Food and Agriculture Organization – FAO, World Health Organization – WHO. (1998). *Report of a joint FAO/WHO expert consultation* (FAO Food and Nutrition Paper, No. 66). Rome: FAO/WHO. Retrieved from http://www.fao.org/docrep/w8079E/w8079e00.htm

Goñi, I., Garcia-Diz, L., Mañas, E., & Saura-Calixto, F. (1996). Analysis of resistant starch: a method for foods and food products. *Food Chemistry*, 56(4), 445-449. http://dx.doi.org/10.1016/0308-8146(95)00222-7.

Hanhineva, K., Törrönen, R., Bondia-Pons, I., Pekkinen, J., Kolehmainen, M., Mykkänen, H., & Poutanen, K. (2010). Impact of dietary polyphenols on carbohydrate metabolism. *International Journal of Molecular Sciences*, 11(4), 1365-1402. http://dx.doi.org/10.3390/ijms11041365. PMid:20480025.

Hodge, A. M., English, D. R., O'Dea, K., & Giles, G. G. (2004). Glycemic index and dietary fiber and the risk of type 2 diabetes. *Diabetes Care*, 27(11), 2701-2706. http://dx.doi.org/10.2337/diacare.27.11.2701. PMid:15505008.

Ilyasoğlu, H., & Arpa Zemzemoğlu, T. E. (2021). Effect of brewing conditions on sensorial and antioxidant properties of linden tea. *Journal of Culinary Science & Technology*. In press. http://dx.doi.org/10.1080/15428052.2021.1972886.

International Diabetes Federation – IDF. (2021). *IDF diabetes atlas*. Brussels. Retrieved from https://diabetesatlas.org/

International Organization for Standardization – ISO. (2008). *ISO, 26642:2010: food products: determination of the glycemic index (GI) and relevant classification*. Geneva: ISO.

Kamstrup, D., Berthelsen, R., Sassene, P. J., Selen, A., & Müllertz, A. (2017). In vitro model simulating gastro-intestinal digestion in the pediatric population (neonates and young infants). *AAPS PharmSciTech*, 18(2), 317-329. http://dx.doi.org/10.1208/s12249-016-0649-1. PMid:27796909.

Kim, Y., Keogh, J. B., & Clifton, P. M. (2016). Polyphenols and glycemic control. *Nutrients*, 8(1), 17. http://dx.doi.org/10.3390/nu8010017. PMid:26742071.

Kismiroğlu, C., Cengiz, S., & Yaman, M. (2020). AMPK'nin biyokimyasi: etki mekanizmalari ve diyabetin tedavisindeki önemi. *Avrupa Bilim ve Teknoloji Dergisi*, (18), 162-170.

Kobayashi, Y., Suzuki, M., Satsu, H., Arai, S., Hara, Y., Suzuki, K., Miyamoto, Y., & Shimizu, M. (2000). Green tea polyphenols inhibit the sodium-dependent glucose transporter of intestinal epithelial cells by a competitive mechanism. *Journal of Agricultural and Food Chemistry*, 48(11), 5618-5623. http://dx.doi.org/10.1021/jf0006832. PMid:11087528.

Koh, L. W., Wong, L. L., Loo, Y. Y., Kasapis, S., & Huang, D. (2010). Evaluation of different teas against starch digestibility by mammalian glycosidases. *Journal of Agricultural and Food Chemistry*, 58(1), 148-154. http://dx.doi.org/10.1021/jf903011g. PMid:20050703.

Krishnakumar, I. M., Issac, A., Johannah, N. M., Ninan, E., Maliakel, B., & Kuttan, R. (2014). Effects of the polyphenol content on the anti-diabetic activity of *Cinnamomum zeylanicum* extracts. *Food & Function*, 5(9), 2208-2220. http://dx.doi.org/10.1039/C4FO00130C. PMid:25051315.

Loizzo, M. R., Pugliese, A., Bonesi, M., Tenuta, M. C., Menichini, F., Xiao, J., & Tundis, R. (2016). Edible flowers: a rich source of phytochemicals with antioxidant and hypoglycemic properties. *Journal of Agricultural and Food Chemistry*, 64(12), 2467-2474. http://dx.doi.org/10.1021/acs.jafc.5b03092. PMid:26270801.

Ludwig, D. S. (2002). The glycemic index: physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. *Journal of the American Medical Association*, 287(18), 2414-2423. http://dx.doi.org/10.1001/jama.287.18.2414. PMid:11988062.

Matsui, T., Tanaka, T., Tamura, S., Toshima, A., Tamaya, K., Miyata, Y., Tanaka, K., & Matsumoto, K. (2007). α-Glucosidase inhibitory profile of catechins and theaflavins. *Journal of Agricultural and Food Chemistry*, 55(1), 99-105. http://dx.doi.org/10.1021/jf0627672. PMid:17199319.

Matsumoto, N., Ishigaki, F., Ishigaki, A., Iwashina, H., & Hara, Y. (1993). Reduction of blood glucose levels by tea catechin. *Bioscience, Biotechnology, and Biochemistry*, 57(4), 525-527. http://dx.doi.org/10.1271/bbb.57.525.

Najafian, M. (2015). The effects of curcumin on alpha amylase in diabetic rats. *Zahedan Journal of Researches in Medical Sciences*, 17(12), e5198. http://dx.doi.org/10.17795/zjrms-5198.

Odenigbo, A., Rahimi, J., Ngadi, M., Amer, S., & Mustafa, A. (2012). Starch digestibility and predicted glycemic index of fried sweet potato cultivars. *Functional Foods in Health and Disease*, 2(7), 280-289. http://dx.doi.org/10.31989/ffhd.v2i7.83.

Pekcan, G., Şanlıer, N., Baş, M., Başoğlu, S., & Acar Tek, N. (2016). *Türkiye Beslenme Rehberi 2015 (TÜBER)*. Ankara: Sağlık Bakanlığı.

Qin, B., Panickar, K. S., & Anderson, R. A. (2010). Cinnamon: potential role in the prevention of insulin resistance, metabolic syndrome, and type 2 diabetes. *Journal of Diabetes Science and Technology*,

4(3), 685-693. http://dx.doi.org/10.1177/193229681000400324. PMid:20513336.

Račková, L., Košťálová, D., Bezáková, L., Fialová, S., Bauerová, K., Tóth, J., & Obložinský, M. (2009). Comparative study of two natural antioxidants, curcumin and *Curcuma longa* extract. *Journal of Food and Nutrition Research*, 48(3), 148-152.

Thondre, P. S. (2013). Food-based ingredients to modulate blood glucose. *Advances in Food and Nutrition Research*, 70, 181-227. http://dx.doi.org/10.1016/B978-0-12-416555-7.00005-9. PMid:23722097.

Törrönen, R., Sarkkinen, E., Tapola, N., Hautaniemi, E., Kilpi, K., & Niskanen, L. (2010). Berries modify the postprandial plasma glucose response to sucrose in healthy subjects. *British Journal of Nutrition*, 103(8), 1094-1097. http://dx.doi.org/10.1017/S0007114509992868. PMid:19930765.

Wiemer, K. (2018). Breakfast cereals. In M. G. Venkatesh Mannar & R. F. Hurrell (Eds.), *Food fortification in a globalized world* (pp. 183-191). London: Academic Press. http://dx.doi.org/10.1016/B978-0-12-802861-2.00019-5.

Williamson, G. (2013). Possible effects of dietary polyphenols on sugar absorption and digestion. *Molecular Nutrition & Food Research*, 57(1), 48-57. http://dx.doi.org/10.1002/mnfr.201200511. PMid:23180627.

Wilson, T., Singh, A. P., Vorsa, N., Goettl, C. D., Kittleson, K. M., Roe, C. M., Kastello, G. M., & Ragsdale, F. R. (2008). Human glycemic response and phenolic content of unsweetened cranberry juice. *Journal of Medicinal Food*, 11(1), 46-54. http://dx.doi.org/10.1089/jmf.2007.531. PMid:18361737.

Yaman, M., Sargın, H. S., & Mızrak, Ö. F. (2019). Free sugar content, in vitro starch digestibility and predicted glycemic index of ready-to-eat breakfast cereals commonly consumed in Turkey: an evaluation of nutritional quality. *International Journal of Biological Macromolecules*, 135, 1082-1087. http://dx.doi.org/10.1016/j.ijbiomac.2019.06.037. PMid:31176861.

Zhang, G., & Hamaker, B. R. (2009). Slowly digestible starch: concept, mechanism, and proposed extended glycemic index. *Critical Reviews in Food Science and Nutrition*, 49(10), 852-867. http://dx.doi.org/10.1080/10408390903372466. PMid:19960393.