The Effect of Pomegranate (Punica granatum L.) Peel and Juice Addition to Bread Varieties on In Vitro Estimated Glycemic Index, Hydrolysis Index and Sensory Properties*

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Abstract

Aim: This study aims to compare the effect of enrichment of white and whole wheat breads with pomegranate peel (PP) and pomegranate juice (PJ) on glycemic index (GI), hydrolysis index (HI) and sensory properties of bread with standard white bread in line with sustainable nutrition approach.

Method: Six different samples were prepared by adding PP and PJ to bread: (1.) White Bread (100 g), (2.) White Bread (95 g) + PP (5 g), (3.) White Bread (90 g) + PP (5 g) + PJ (110 g), (4.) Whole Wheat Bread (100 g), (5.) Whole Wheat Bread (95 g) + PP (5 g) and (6.) Whole Wheat Bread (90 g) + PP (5 g) + PJ (110 g). The HI value of the test food was calculated by comparing it to the reference food. The estimated GI analyses of the samples were performed by spectrophotometric-based methods under *in vitro* conditions. Afterwards, sensory analyses such as color, smell, taste etc. of these samples were evaluated by 11 panelists and the data obtained were analyzed with SPSS package program.

Results: The estimated GI values of the samples showed a non-significant decrease compared to standard white bread ($p>0.05$). Whole wheat bread with added PP was found to have the lowest GI among the samples (84.5 ± 0.5). The HI (88.4 ± 1.0) of whole wheat bread with PP and PJ was statistically lower than the HI (100.0 ± 1.2) of standard white bread, but higher than the HI (84.5 ± 0.5) of whole wheat bread with only PP. As a result of sensory analysis, significant results were obtained only for sourness ($p=0.014$) and hardness ($p=0.011$) parameters of whole wheat bread. Whole wheat bread with added PP was the most liked and most suitable for consumption (4.10 ± 0.70) ($p>0.05$).

Conclusion: Whole wheat bread with PP had lower *in vitro* estimated glycemic index and was the most liked bread in terms of sensory properties.

Keywords: Sustainability, pomegranate peel, glycemic index, hydrolyzed index, bread.

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ETHICAL STATEMENT: Ethics committee approval was obtained from Marmara University, Ethics Committee (Date: 12/12/2022, Number: 2022/180) and the study was conducted in accordance with the principles of the Declaration of Helsinki.

Ekmek Çeşitlerine Nar (*Punica granatum* L.) Kabuğu ve Suyu İlavesinin *İn Vitro* Tahmini Glisemik İndeks, Hidroliz İndeksi ve Duyusal Özellikler Üzerine Etkisi

Öz

Amaç: Bu çalışma, sürdürülebilir beslenme yaklaşımı doğrultusunda, beyaz ve tam buğday ekmeğinin nar kabuğu (NK) ve nar suyu (NS) ile zenginleştirilmesini; glisemik indeks (GI) ve hidroliz indeksinin (HI) standart beyaz ekmeğe kıyasla azaltılmasını ve ekmeğin duyusal özelliklerinin değerlendirilmesini amaçlamaktadır.

Yöntem: Ekmeğe NK ve NS eklenerek 6 farklı numune hazırlanmıştır: (1) Beyaz Ekmek (100 g), (2) Beyaz Ekmek (95 g) + NK (5 g), (3) Beyaz Ekmek (90 g) + NK (5 g) + NS (110 g), (4) Tam Buğday Ekmeği (100 g), (5) Tam Buğday Ekmeği (95 g) + NK (5 g) ve (6) Tam Buğday Ekmeği (90 g) + NK (5 g) + NS (110 g). Test besinin HI değeri referans besin ile karşılaştırılarak hesaplanmıştır. Numunelerin tahmini GI analizleri *in vitro* koşullarda spektrofotometrik temelli yöntemlerle gerçekleştirilmiştir. Daha sonra bu numunelerin renk koku tat vb. duyusal analizleri 11 panelist tarafından değerlendirilmiş ve elde edilen veriler, SPSS paket programı ile analiz edilmiştir.

Bulgular: Çalışmada kullanılan numunelerin tahmini GI değerleri standart beyaz ekmeğe kıyasla anlamlı olmayan bir düşüş göstermiştir ($p>0,05$). Nar kabuğu eklenmiş tam buğday ekmeğin numuneler arasında en düşük GI'e sahip olduğu görülmüştür (84,5 ± 0,5). NK ve NS eklenmiş tam buğday ekmeğinin HI (88,4 ± 1,0) değeri, standart beyaz ekmeğin HI (100,0 ± 1,2) değerinden istatistiksel olarak daha düşük bulunmuş, ancak yalnızca NK eklenmiş tam buğday ekmeğinin HI (84,5 ± 0,5) değerinden daha yüksek olduğu saptanmıştır. Duyusal analiz sonucunda yalnızca tam buğday ekmeğinin ekşilik ($p=0,014$) ve sertlik ($p=0,011$) parametrelerinde anlamlı sonuçlar elde edilmiştir. En çok beğenilen ve tüketim açısından en uygun bulunan ekmeğin, NK eklenen tam buğday ekmeği olduğu belirlenmiştir (4,10 ± 0,70) ($p>0,05$).

Sonuç: Nar kabuğu eklenen tam buğday ekmeğinin *in vitro* tahmini glisemik indeksinin daha düşük ve duyusal özellikler açısından en çok beğenilen ekmek olduğu belirlenmiştir.

Anahtar Sözcükler: Sürdürülebilirlik, nar kabuğu, glisemik indeks, hidrolize indeks, ekmek.

Introduction

Sustainable nutrition is crucial for global development, protecting biodiversity, and delivering natural food resources. The processing of fruits and vegetables leaves excessive waste by-products such as peel, seeds, and pulp[1]. The Food and Agriculture Organization (FAO) aims to reduce food waste by 50% by using food by-products as materials[2]. The use of food by-products, rich in nutrients and bioactive compounds, is being explored for their health benefits. While they may increase glycemic index, it's crucial to evaluate their palatability and consumer acceptance[3].

Pomegranate (*Punica granatum* L.) is a member of the Punicaceae family, of which Türkiye is one of the leading countries in production. During industrial processing, 50% of the pomegranate fruit is discarded as peel, pulp, and seeds[4]. Pomegranate is rich in bioactive components and antioxidants[5] making it valuable in supplements and medicine for its potential disease-protective effects[6].

Pomegranate peel, despite being a by-product, contains bioactive components that can be used to create high-nutrient food products[7,8]. The phenolic acids in the peel, which make up about half of the fruit, have antioxidant and anti-inflammatory properties[9].

The Glycemic Index (GI) classifies carbohydrate-rich foods, helping people make appropriate choices for their health. The glycemic response of a food depends on the number of components present in it, such as dietary fiber, protein, and fat[10]. High-glycemic carbohydrates have a GI value over 70[11]. The Hydrolyzed Index (HI) measures

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the speed of carbohydrate digestion in the gastrointestinal tract, with high HI often indicating rapid absorption and breakdown of carbohydrates[12]. The GI measures the rate at which a carbohydrate-containing food raises blood glucose levels, while the hygroscopic index (HI) evaluates the breakdown of carbohydrates during digestion[10]. Foods with a high HI often correspond to high GI values, indicating rapid digestion and absorption, leading to spikes in blood glucose levels[13]. The modulation of glycemic levels and the regulation of cellular glucose uptake are crucial elements in preserving health[14]. Hyperglycemia has been demonstrated to induce reactive oxygen species (ROS) production, thereby accentuating the interconnection between hyperglycemia, oxidative stress, and inflammation. This interplay has been evidenced to precipitate a spectrum of metabolic disorders affecting the liver, adipose tissue, skeletal muscle, kidneys, cardiovascular system, retina, and other organs[15].

Food compounds such as polyphenols, flavonoids, and tannins are suggested as natural α-amylase and α-glucosidase inhibitors to regulate dietary glucose metabolism, as blood glucose is primarily derived from dietary carbohydrate hydrolysis[16]. White bread, the primary carbohydrate source consumed in Türkiye is a high-GI product that undergoes rapid digestion and absorption, and its lack of glycemic control can contribute to elevated blood sugar levels[17,18]. It has been shown that polyphenols can inhibit the activity of *in vitro* amylolytic enzymes and control GI[19]. In the literature, pomegranate juice (PJ) has also been found to be effective in the prevention of type 2 diabetes by showing hypoglycemic activity and antidiabetic effect. The hypoglycemic and antidiabetic effects of PJ are primarily attributed to its rich content of bioactive compounds, particularly polyphenols such as ellagitannins, ellagic acid, and flavonoids[20].

In addition, another strategy to reduce the GI of bread is incorporating fiber-rich flours or pure dietary fiber[21]. The most abundant component in pomegranate peel (PP) is dietary fiber, which can range from 33% to 62%, making PP a natural and rich source of fiber[22]. It is believed that incorporating PP into breads may influence glycemic response by increasing their fiber content and antioxidant capacity, while the inclusion of PJ could further enhance these effects. This study aims to assess the impact of enriching white and whole wheat breads with PP and PJ on the *in vitro* estimated glycemic index (eGI), HI and sensory properties of these breads, comparing them with standard white bread, within the context of sustainable nutrition.

Material and Methods

Preparation of Samples

Wheat flour (Type 750) (0.75% ash, 10.5% protein, and 14.5% moisture), whole wheat flour (1.2% ash, 11% protein and 14.5% moisture), fresh yeast, salt, drinking water, olive oil, pomegranate peel (PP) and pomegranate juice (PJ) were used as ingredients in this study. No preservatives were added. Breads were made with Russell Hobbs 18036-56 RH Classic Bread Making Machine.

Pomegranates (*Punica granatum* L.) were obtained from the local market. After pomegranates were washed and they were pressed with a juicer to obtain pomegranate juice. After being filled into 1 L glass bottles, they were tightly closed and stored at -18°C. The peels of the same pomegranates were cut into small pieces and divided into small

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containers made of aluminum foil. They were dried in a sterilization device (Megaterm M160 16 Lt Manual Dry Air Sterilizer) at 50 °C for about 6 h. The dried pomegranates were grinded and stored at 0-4°C.

The mixture of pomegranate juice (110 g) was added as a substitute for water, and pomegranate peel powder (5 g) was added to the bread dough mixture as a substitute for flour in the following amounts according to the ratios used in the reference studies[23,24]. The visuals of the samples listed below are given in Figure 1 and the content of bread samples are shown in Table 1.

Table 1. Content of Bread Samples with Pomegranate Peel (PP) and Pomegranate Juice (PJ)

Sample type	Weight (g)	Pomegranate Peel (PP) (g)	Pomegranate Juice (PJ) (g)
White Bread	100	0	0
White Bread + PP (5 g)	95	5	0
White Bread + PP (5 g) + PJ (110 g)	90	5	110
Whole Wheat Bread	100	0	0
Whole Wheat Bread + PP (5 g)	95	5	0
Whole Wheat Bread + PP (5 g) + PJ (110 g)	90	5	110

Figure 1. Bread samples used in the study

In Vitro Estimated Glycemic Index

For the *in vitro* estimated GI (eGI) method, the analytical methods of Englyst et al. (1999)[25] and Gibson et al. (2011)[26] were used as references. The data obtained in these studies were calculated according to a study by Goni et al. (1997)[27].

For eGI determination, approximately 1 g sample was weighed into a 50 ml tube and 0.1M phosphate buffer (pH 6.9) was added and mixed thoroughly in vortex. Then 20 ml of phosphate buffer was added. The pH of the mixture was adjusted to 2.5 with orthophosphoric acid and 1 ml of pepsin enzyme was added. The mixture was kept in a shaking water bath at 37°C for 1 hour and pH was adjusted to 6.8 with potassium hydroxide solution. 2 mL alpha amylase enzyme was added. The prepared solution was transferred into a dialysis tube and taken for 500 ml of buffer solution. From the solution in the shaking water bath, 0.2 ml was taken at 0, 15, 30, 45, 60, 90, 120 minutes, the solution was treated with the D-Glucose assay kit (GOPOD) solution, and the amount of glucose was calculated, and the starch amount was determined by multiplying the result by 0.9.

The values obtained were compared with total starch and the % soluble starch content was also found. White bread as a reference food was processed in the same way. The area under the reference food was accepted as 100.

In Vitro Hydrolysis Index

The HI value of the test food was calculated by comparing it to the reference food. The HI value of white bread was accepted as 70. In the calculation, the HI values of other tested foods were multiplied by 0.7[27]. The *in vitro* GI value of foods was calculated according to the following formula:

HI = Area (test food) / Area (reference food) x 100

eGI = 39,71 + 0,549 x HI

Sensory Analysis of Samples

Sensory analysis of the samples was carried out in May 2023 with 11 individuals aged 18-65 years, who volunteered to participate in the study. Individuals with food allergies, colds or flu, recent cases of SARS-CoV-2 infection, impaired taste and smell, and smokers were excluded from participation. The prepared samples were evaluated by the panelists using a single-blind method, whereby the assessors were unaware of the identity of the samples.

Analyses were carried out according to the paired comparison method. A questionnaire form with a scoring scale was used. The panelists tasted the samples and gave a score from 1 to 5 (very good, good, undecided, poor, and very poor) in the sensory analysis questionnaire. In the questionnaire, viscosity, consistency, color, smell, taste, texture and general acceptability criteria of the products were scored by Likert method. The arithmetic mean of the scores for each attribute was taken to calculate the general acceptability score. Panelists were asked to neutralize the taste with water before tasting each sample.

This study was approved ethically by the Marmara University Faculty of Health Sciences Non-Invasive Clinical Studies Ethics Committee (No: 2022/180) and the research was conducted following the principles stated in the Helsinki Declaration. Informed Consent Form was signed by all participants before sensory analysis.

Statistical Analysis

The data obtained from this study was analyzed with Statistical Package for the Social Sciences (SPSS) 28.0 statistical software. The difference between the samples was determined by ANOVA test and Tukey post-hoc test was used for two group comparisons. Data were expressed as mean ± standard deviation. For all analyses, p value < 0.05 was considered statistically significant.

Results

In this study, the HI and eGI of seven samples were calculated, including a standard white bread sample that was used as a reference (Table 2). Although no significant decrease was observed among the white bread samples, it was found that the addition of PP to whole wheat bread decreased the HI values significantly ($p < 0.05$). The sample with the lowest eGI value among all samples was PP added whole wheat bread (60.3 ± 1.1). Similarly, when the HI values were analyzed, the PP added whole wheat bread had the lowest HI value (84.5 ± 0.5). It was found that the HI (88.4 ± 1.0) value of PP and PJ added whole wheat bread was statistically lower than the HI (100.0 ± 1.2) value of standard white bread, but higher than only PP added whole wheat bread.

Table 2. Calculated hydrolysis index and estimated glycemic index for breads

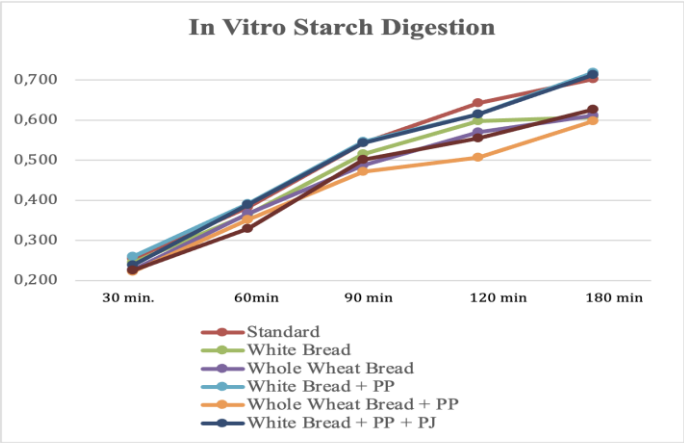
Sample	**HI[1] ± SD (%)**	**eGI[1] ± SD (%)**
Standard White Bread	100.0 ± 1.2[a]	66.3 ± 1.1[a]
White Bread	92.4 ± 0.8[b]	63.3 ± 0.6[ab]
Whole Wheat Bread	89.6 ± 1.1[c]	62.2 ± 2.0[b]
White Bread + PP	99.7 ± 0.9[a]	66.1 ± 1.0[a]
Whole Wheat Bread + PP	84.5 ± 0.5[d]	60.3 ± 1.1[b]
White Bread + PP + PJ	98.6 ± 0.5[a]	65.7 ± 1.0[a]
Whole Wheat Bread + PP + PJ	88.4 ± 1.0[c]	61.8 ± 0.6[b]

HI - hydrolysis index; eGI - estimated glycemic index; PP - Pomegranate Peel; PJ - Pomegranate Juice

[1] The different letters in the same column indicate that there are statistical differences between the values (ANOVA $p < 0.05$. Tukey's test).

Figure 2 shows the starch release as a result of *in vitro* eGI determination. According to the graph, it is seen that whole wheat breads show a more balanced release compared to white breads. PP added whole wheat bread showed the lowest starch release (0,222) at the end of the 30th minute. PP and PJ added whole wheat bread showed the lowest starch release (0.329) at the end of 60 minutes. Only PP added whole wheat bread showed the lowest starch release (0.598) at the end of the 180th minute.

Fig 2. *In vitro* starch digestion



To evaluate the sensory analyses of the bread samples, a total of 11 panelists were included in the study. Of these, 90.9% (n=10) were female and 9.1% (n=1) was male. The average age of the panelists was 33.5 ± 2.73 years.

Sensory analysis results of bread samples are shown in Table 3. A statistically significant difference was found in the sourness parameter of the bread samples (p = 0.014). White bread (4.00 ± 0.77) was statistically more favored. With the addition of PP to whole wheat bread, although the liking of sourness did not change statistically, it increased and became numerically the closest sample to plain white bread. The degree of sourness of PP and PJ added whole wheat bread (2.64 ± 1.43) was found to be statistically less favorable than the others (respectively; p=0.014 and p=0.011).

A statistically significant difference was found in the hardness parameter of bread samples (p = 0.011). Plain white bread (4.19 ± 0.60) was statistically most liked. The closest score to plain white bread was found to be PP and PJ added whole wheat bread (4.00 ± 0.89).

No statistically significant difference was found in the general acceptance parameter of the bread samples (p= 0.159). When the general acceptance criterion was evaluated, whole wheat bread enriched with PP achieved the highest preference score (4.10 ± 0.70) among the samples, though the difference was not statistically significant (p > 0.05).

Table 3. Sensory analysis results of bread samples

Sensory characteristics	Bread samples						*p* value
	White Bread	Whole Wheat Bread	White Bread + PP	Whole Wheat Bread + PP	White Bread + PP + PJ	Whole Wheat Bread + PP + PJ	
Viscosity	3.82 ± 0.75	3.73 ± 0.79	4.10 ± 0.54	3.91 ± 0.83	3.82 ± 0.75	3.91 ± 0.70	0.910
Consistency	4.00 ± 0.63	3.55 ± 0.93	4.10 ± 0.54	4.00 ± 0.63	3.91 ± 0.54	3.91 ± 0.54	0.668

Smell	4.00 ± 0.89	3.64 ± 0.67	3.73 ± 1.01	4.00 ± 1.10	3.55 ± 0.82	3.37 ± 1.36	0.557
Taste	3.64 ± 0.50	3.64 ± 1.21	3.00 ± 1.18	3.82 ± 1.40	3.00 ± 1.18	3.19 ± 1.25	0.335
Sourness	4.00^{a}± 0.77	3.73^{ab}± 0.65	2.82^{b} ±1.25	3.91^{a} ± 1.04	2.82^{b}±1.25	2.64^{b}±1.43	**0.014**
Tissue	3.91 ± 0.83	3.73 ± 0.79	3.64 ± 0.81	3.91 ± 0.94	3.64 ± 0.81	4.10 ± 0.70	0.698
Hardness	4.19^{a}± 0.60	3.73^{ab}± 0.65	3.19^{b}±0.98	3.19^{a}± 0.60	3.19^{b}±0.98	4.00^{a}±0.89	**0.011**
Pore structure	4.00 ± 0.63	3.73 ± 0.79	4.19 ± 0.60	3.73 ± 0.90	4.10 ± 0.83	3.73 ± 0.79	0.636
Shell color	3.82 ± 0.75	4.00 ± 1.00	3.55 ± 0.69	4.19 ± 0.75	3.91 ± 0.83	4.19 ± 0.40	0.289
Interior Color	4.28 ± 0.90	4.00 ± 0.63	4.00 ± 0.89	4.10 ± 0.83	4.10 ± 0.70	4.00 ± 0.63	0.859
General acceptance	3.73 ± 0.90	3.64 ± 0.81	3.19 ± 0.98	4.10 ± 0.70	3.19 ± 0.98	3.37 ± 1.03	0.159

PP - Pomegranate Peel; PJ - Pomegranate Juice

[1]The different letters in the same rows indicate that there are statistical differences between the values (ANOVA $p < 0.05$. Tukey's test)

Discussion

This study was conducted to enrich white and whole wheat bread with the peel and juice of pomegranate fruit within the scope of sustainable nutrition and to calculate the eGI and HI compared to standard white bread. Among the breads, the PP added whole wheat bread was found to have the lowest eGI. Also, the sensory analysis showed that the PP added whole wheat bread was the sample with the highest score, according to the general acceptance criterion.

Dietary fiber, a type of slowly digestible carbohydrate, has a low GI and plays a major role in improving public health[28]. The International Carbohydrate Quality Consortium panel has endorsed low GI as an effective approach to reduce postprandial glycemic response[29]. In studies examining the use of PP, it has been observed that the inclusion of PP in cookies and biscuits[30-32], breads[33-37] and cakes[38] has resulted in an increase in dietary fiber, phenols and antioxidant activity. Dietary fiber delays carbohydrate absorption, which helps to prevent increases in insulin levels, improve glycemic control, and reduce the GI of foods[39]. In a study by Garcia et al. (2023)[40], the GI value of the control bread was accepted as 100, the GI value for bread with 2.5% PP was 78 and the GI value for bread with 5% PP was 72 and a statistically significant difference was found. In this study, the eGI of white bread enriched with 5% PP was higher than the control bread, whereas the eGI of whole wheat bread enriched with 5% PP was lower than plain whole wheat bread. These findings suggest that the addition of PP to bread formulations may alter the glycemic response depending on the composition and properties of the bread.

Mirab et al. (2020)[41] produced sponge cake using PP (0.5, 1 and 1.5 g/100 g) and evaluated α-glucosidase and α-amylase activities. As a result of the study, starch digestibility and glycemic index in sponge cake decreased by 43.5% and 44%, respectively. Similarly, in our study, a decrease in starch release was observed in whole wheat bread with PP and a decrease in eGI value was determined.

Pomegranate Juice has shown to have decreasing effects on acute and 3 h postprandial glycemic effect in both healthy and diabetic individuals[42,43]. In a previous study, the reduced glycemic response after consumption of PJ-added bread was explained by the fact that polyphenols derived from pomegranate have the potential to further modulate carbohydrate metabolism[44]. However, in contrast to previous clinical studies, in this study, the addition of PJ in addition to PP made no significant difference on eGI in bread samples. This difference between *in vitro* eGI and clinical studies suggests that PJ may increase the glycemic index of bread due to its low fiber and simple carbohydrate content, but the polyphenol and other antioxidant components present in PJ may reduce the glycemic response by affecting glucose metabolism. In a recent study where pomegranate peel powder (8% PP) was added to muffins, the total phenols increased from 0.92 to 12.5 mg GAE/100 g, total tannins from 0.2 to 8.27 mg GAE/100 g, and an increase in *in vitro* antioxidant activity was observed. Further *in vivo* studies are needed to determine the effects of polyphenols and antioxidants on the glycemic index of the breads.[45]

Although studies show that PP in bakery products ranges from 1% to 20%[30-38], studies have shown that 2.5% to 5% PP added to bread is acceptable to consumers[34,35,40]. Ismail et al. (2014)[30] reported that enrichment of cookies with PP remained acceptable below 6%, but the overall acceptance significantly reduced when the added PP increased. In our study, the highest overall acceptability was found in whole wheat bread with 5% PP. Although the addition of PP to white bread led to a decrease in the overall acceptance criterion, the scores of all samples were statistically similar. The reason for no significant difference in the overall acceptability level of the addition of PP and PJ to the breads, may be the slightly sour taste and dark color from the additions of PP and PJ are similar to the traditional Turkish breads.

Bread texture, particularly hardness, can be influenced by the addition of functional ingredients such as PP. Bourekoua et al. (2018)[46] reported that the samples with higher addition of pomegranate seed powder were harder. In this study, PP added white bread, and PP and PJ added white bread were rated lower in hardness parameter compared to plain white bread in accordance with the study conducted by Bourekoua et al. (2018).[46] In contrast, in our study, PP added whole wheat bread and PJ and PP added whole wheat bread were rated higher in terms of hardness than plain whole wheat bread. This may be since plain white bread is softer than plain whole wheat bread.

Pomegranate peel, in addition to its use in bakery products, serves as a natural antioxidant and biopreservative in dairy, meat, poultry, and fish products due to its high phenolic content. It can replace synthetic preservatives and enhance the antioxidant properties of packaging materials.[47] A study by Giri et al.[45] suggests that PP powder can effectively substitute chemical preservatives in muffins, although it may impart a slightly

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bitter taste. In our study, the addition of PP to white bread did not affect the sourness score in sensory analysis. Furthermore, the addition of pomegranate peel's soluble dietary fiber to sweet potato starch has been shown to reduce its digestibility and increase resistant starch content, which may help reduce the glycemic response of starch-based foods.[48]

In other research, by-products such as grape pomace and pecan shells were added to bread at varying ratios, demonstrating a reduction in the GI compared to control bread.[49] Similarly, a study on Picralima nitida fruit found that the whole fruit powder exhibited the lowest estimated glycemic load (eGL), further supporting the potential of fruit by-products as effective antidiabetic food additives.[50] In this study, the addition of pomegranate peel and juice to whole wheat bread appears to be more effective in reducing the eGI. These findings highlight the value of using fruit by-products in enhancing both the nutritional quality and health benefits of food.

Strengths and Limitations

The study provides a comprehensive analysis by integrating *in vitro* eGI analysis and sensory evaluations to examine the effects of PP and PJ on bread. It highlights the influence of different bread formulations (white, whole wheat, and PP/PJ-added) on the eGI and HI, providing valuable insights into how pomegranate derivatives affect the nutritional profile of bread. Sensory evaluations, including assessments of taste, color, and texture conducted by trained panelists, offer critical information on consumer preferences. Finally, the study contributes to sustainability by utilizing PP and PJ to reduce food waste while enhancing the nutritional value of bread. This approach promotes the efficient use of environmental resources and supports the development of functional foods that are both health-beneficial and environmentally friendly.

However, the study has some limitations. While the eGI reduction effect was evaluated through the incorporation of PP powder, the analysis of fiber content in the final bread products was not conducted. Also, the addition of PP altered the expected soft texture of the bread, and the absence of a nutritional analysis of the pomegranates used constitutes another limitation. Despite these limitations, the findings underscore the potential health benefits of incorporating natural by-products, such as PP, into bread products, and highlight the need for further research to explore the integration of such ingredients in food systems.

Conclusion

Non-consumed dietary fiber sources such as PP can be functionally effective and can be utilized. In this study, whole wheat bread with PP was found to have the lowest *in vitro* eGI among the samples. When the sensory analysis results were evaluated according to the general acceptability criterion, the whole wheat bread with PP was the sample with the highest point.

Further clinical studies are required to explore the potential benefits of these products and their impact on chronic diseases and potential side effects. Additionally, higher levels of PP may be needed to effectively reduce the glycemic index of bread. However, it is crucial to also assess the palatability and overall acceptability of PP added products to ensure their practical use.

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