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RHEOLOGICAL AND WATER-HOLDING CHARACTERISTICS OF YOGHURTS ENRICHED WITH FRUIT BY-PRODUCTS

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Abstract

Fruit peels are food waste that is a rich source of dietary fiber, terpenes, and phenolic compounds. Since fruit peels are renewable, sustainable, and affordable, they can be included as natural resources in product enrichment in the food industry. This study aimed to investigate the enrichment of yogurt with fruit peel powders of lemon (LP), orange (OP), and pomegranate (PP).

Unheated and heated fruit peel powder solutions were added to the yogurt. The water holding capacity (WHC) of the yogurt samples was determined by determining the weight of the serum retained after centrifugation and calculated as a percentage. The pH value of the yogurt samples was measured using a pH meter. The rheological properties of the yogurt samples were determined by using a rotational rheometer with a cone-plate sensor by applying a stress sweep test and a controlled ramped shear rate test.

The rheological properties and WHC of yogurts enriched with heated fruit peel powder solutions were found to be higher than unheated samples. While there was no significant difference between the pH values, there was a difference between the WHC of yogurt samples. Yogurt enriched with heated LP resulted in the highest WHC and apparent viscosity. The shear stress increased more with the shear rate in heated LP-enriched yogurt. Yoghurts enriched with heated OP and LP had the highest consistency coefficient and thixotropy. The yield stress of the yogurt enriched with heated OP was found to be the highest.

Fruit peels were shown to be a practical way of enriching yogurt with functional food components such as fiber, phenolic compounds, and others. They not only contributed to nutritional value and flavor but also improved the rheological properties and water-holding capacity of the product.

Key words*: Yogurt, Rheology, Fruit peel powder, Waste Recycling, Sustainability.*

1. Introduction

Yogurt is a fermented dairy product produced by inoculating lactic acid bacteria (*Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*) into milk. Yogurt is widely consumed around the world especially in Eastern Europe, the Balkans, and the Middle East due to its high nutritional value, useful bacteria, and wide product range [1]. Depending on the composition of milk, yogurt is an excellent source of protein, minerals (calcium, magnesium, phosphorus, zinc), and vitamins (riboflavin, thiamin, vitamin B12, folate, niacin) [2]. Although yogurt contains many nutrients, studies in recent years have focused on enriching yogurts with the addition of functional components [3].

Fruits are healthy food sources rich in nutrients and functional components. The addition of fruits and fruit ingredients has been practiced to mask the acidic taste of yogurt, add dietary fiber, and increase functional value with polyphenols. Accordingly, black mulberry puree [4], grape skin flour [5], mulberry pomace extract [6], pomegranate juice [7], rosehip [8], and apple pomace [9] were used to incorporate phenolics and dietary fiber to yogurt. Fortification with fruit ingredients in yogurt can also improve textural properties and water-holding capacity [3]. Enrichment of yogurt with apple pomace decreased the syneresis by half that of the control [9]. The addition of carrot cell wall particles to yogurt increased the firmness and reduced whey loss [10]. Yogurt enriched with soluble dietary fibers from carrots had higher shear stress, viscosity, consistency index, and lower flow behavior index and syneresis compared with control yogurt [11].

Fruit peels resulting from industrial processing are rich in dietary fiber, pectin, and bioactive components. Therefore, the enrichment of yogurt with fruit peels has been investigated to valorize fruit processing wastes as functional ingredients [12]. Pectin from banana-papaya peel improved sensory properties and general acceptance of yogurt [13]. Fortification of yogurt with fiber-rich pineapple peel powder increased firmness and storage modulus [14]. Formulation of yogurt with banana peel extract delayed lipid oxidation during storage [15]. Enrichment with passion fruit peel powder increased the firmness, consistency, and cohesiveness of yogurt [16].

This study aimed to investigate the fortification of yogurt with peel powder of lemon, orange, and pomegranate. The effect of fruit peel powder on the water-holding capacity, pH, and rheological properties of yogurt was examined.

2. Materials and Methods

2.1 Preparation of the fruit peel powders

Fruits and cow milk yogurt (4% fat, 4% protein, and 4.6% carbohydrate) were obtained from a local market in Istanbul, Türkiye. Lemon peels were freeze-dried (FreeZone freeze dryer system, Labconco, USA) for 2 days at -50 ^{0}C and 0.01 mbar pressure. Orange peels and pomegranate peels (peel and albedo) were dried in an oven at 60 ^{0}C for 2 days. Dried fruit peels were finely ground into powder using a small mill grinder (Robert Bosch Hausgeräte, Germany) and stored at 4 ^{0}C for 1 day until analyzed.

2.2 Production of the fruit peel-enriched yoghurts

One g of each powder was mixed with 5 mL of distilled water. The solutions were used as heated and unheated. Unheated fruit peel powder solutions were directly mixed with 50 g of yogurt. Heated fruit peel powder solutions were kept in a water bath at 85 ^{0}C/45 min, cooled immediately using an ice bath, and mixed with 50 g of yogurt. Fruit peel-added yogurts were homogenized (Ultraturrax T18, IKA Werke, Staufen, Germany) at 3,500 rpm for 1 min and stored at 4 ^{0}C for 1 day until analyzed.

2.3 Determination of pH

pH values of the control and fruit peel-enriched yoghurts were measured, using a pH meter (HI 2211 Hanna Instruments, The Netherlands).

2.4 Water holding capacity

The water-holding capacity of the control and fruit peel-enriched yogurts was measured by centrifuge method [4]. Fifteen g of fruit peel-enriched yoghurt was centrifuged at 5,000 x g at 10 ^{0}C for 30 min and the water holding capacity was calculated using equation (1) below:

$$\text{Water holding capacity (\%)} = \frac{\text{Yoghurt (g)} - \text{Separated whey (g)}}{\text{Yoghurt (g)}} \times 100 \quad (1)$$

2.5 Rheological measurements

The rheological properties of the control and fruit peel enriched yogurts after 24 h of production were measured using a rotational rheometer (Haake RheoStress 1, Germany) at 25 ^{0}C with a cone-plate sensor (C35/2, 35 mm diameter, 2^0, Thermo Fisher Scientific, Karlsruhe, Germany) and gap of 0.105 mm by applying controlled ramped shear rate test and stress sweep test.

A controlled ramped shear rate test was carried out by increasing the shear rate linearly from 0.1 to 300 s^{-1}. The flow curves were obtained by increasing the shear rate for 150 sec (upward flow curve) and decreasing it for 150 sec (downward flow curve).

The obtained data from the upward flow curve was fitted to the power law equation (equation 2) to obtain the consistency coefficient and flow behavior index:

$$\tau = k\dot{\gamma}^n \quad (2)$$

Where: τ is the shear stress (Pa), k is the consistency index (Pa.s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the flow behavior index.

The apparent viscosity value was determined from the viscosity value at a shear rate of 50 x s^{-1} in the upward flow curve. Thixotropic behavior of the fruit peel-enriched yogurts was determined by calculating the area of the hysteresis loop between the upward and downward flow curves [17].

A stress sweep test was carried out by applying shear stress between 0 and 1,000 Pa at 0.1 Hz at 25 ^{0}C. The elastic modulus (G') and viscous modulus (G") values were measured. The shear stress value at which elastic and viscous modulus crossed was determined as yield stress.

2.6 Statistical analysis

Effects of fruit peel enrichment on measured properties of the yogurt samples were analyzed using analysis of variance (IBM® SPSS® Statistics 28.0, USA). Means were compared according to the Tukey's test. A significant level of 0.05 was used in the analyses.

3. Results and Discussion

3.1 pH values

There was no significant difference between the pH (~4.3) values of the yogurts ($p > 0.05$). The results were consistent with previous reports. Zahid *et al.*, [18], reported that the addition of fruit peel powder (banana and mango) to yogurt did not change pH. Hayam *et al.*, [19], found that the addition of citrus peels to yogurt resulted in similar acidity to that of control yogurt. Erkaya-Kotan *et al.*, [20], also found that the addition of orange fiber to yoghurt did not change pH.

3.2 Water holding capacity (WHC)

Gel firmness and WHC are considered as the factors indicating the stability of yogurt against syneresis [21]. Syneresis decreases the acceptability of yogurt due to its unpleasant appearance [22]. The yogurt sample enriched with heated LP resulted in the highest WHC while other samples had a similar WHC to that of the control yogurt (Table 1). The fiber contents of the fruit peel are 56.22% for PP, 63.24% for OP, and 64.07% for LP in dry matter [23, 24]. Dietary fibers, especially pectin, had water-holding capacities to use as thickening, texturizing, stabilizing, and gelling agents. The pectin content of fruit peels is 20.75%, 15.25%, and 6.13% for OP, LP, and PP, respectively [25, 26]. Moreover, as the degree of esterification increases, gelation occurs easily in a shorter time. The degree of esterification values is %79.54, %69.67, and % 56.74 for LP, OP, and PP, respectively [26, 27]. The high degree of esterification of LP may be related to the high WHC of the yogurt sample with heated LP.

3.3 Rheological properties

The flow curves of the yogurts are given in Figure 1. The consistency coefficient and flow behavior index values were obtained by the power law model. The flow behavior (n) indices of all the yogurt samples were less than 1 pointing to pseudoplastic non-Newtonian flow behavior (Table 1). The shear stress increased as the shear rate increased. The addition of fruit peels to yogurt resulted in higher shear stress values than those of control yogurt. The shear stress values of yogurt enriched with heated LP were the highest. Accordingly, the apparent viscosity of the heated LP-enriched yogurt was higher than that of the other yogurts. This could be explained by the higher soluble dietary fiber content of heated LP. Similarly, Dong *et al.*, [11], reported that the yogurt supplemented with carrot soluble dietary fiber had higher viscosity and shear stress than control yogurt.

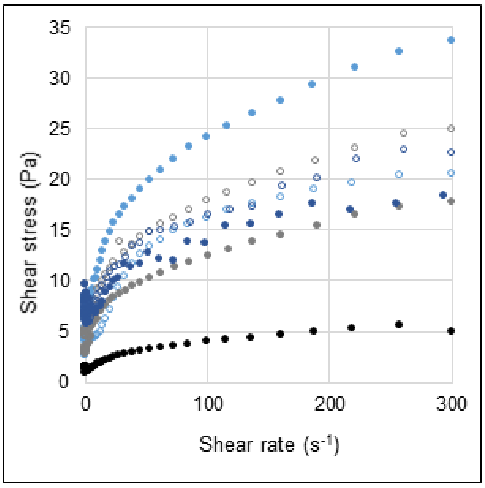

Figure 1. Flow curves of yogurt samples. (•) control; (°) lemon peel; (•) heated lemon peel; (°) pomegranate peel; (•) heated pomegranate peel; (°) orange peel; (•) heated orange peel

The apparent viscosity of the yogurts enriched with fruit peels was higher than that control. The heated LP-enriched yogurt resulted in the highest apparent viscosity (Table 1). The dietary fiber contents in fruit peels especially pectin could increase the apparent viscosity. Similarly, Wang *et al.*, [9], found that the addition of apple pomace increased both soluble and insoluble fiber content and viscosity.

The heated OP-enriched yogurt had the highest value of K and the lowest value of n (Table 1). This indicated that although the consistency was high, a stronger shear-thinning behavior was present possibly due to

Table 1. Water holding capacity and rheological of yogurt samples

	Water holding capacity (%)	Apparent viscosity (50 x s^{-1}, Pas)	Consistency coefficient (K, Pas^n)	Flow behavior index (n)	Thixotropy (Pas^{-1})
Control	65.6 ± 1.1^b	0.12 ± 0.09^b	2.00 ± 1.23^c	0.28 ± 0.02^a	349 ± 47^b
LP	66.6 ± 0.9^b	0.18 ± 0.09^{ab}	3.03 ± 0.49^{bc}	0.26 ± 0.07^a	478 ± 202^b
Heated LP	71.0 ± 0.5^a	0.36 ± 0.01^a	5.53 ± 1.08^{abc}	0.29 ± 0.00^a	966 ± 160^a
PP	65.9 ± 0.2^b	0.26 ± 0.01^{ab}	4.33 ± 0.47^{abc}	0.29 ± 0.01^a	479 ± 91^b
Heated PP	67.6 ± 1.1^b	0.16 ± 0.04^{ab}	2.76 ± 0.58^{bc}	0.28 ± 0.01^a	363 ± 52^b
OP	65.4 ± 0.1^b	0.25 ± 0.02^{ab}	5.64 ± 0.62^{ab}	0.22 ± 0.01^{ab}	499 ± 108^b
Heated OP	66.4 ± 0.2^b	0.20 ± 0.00^{ab}	7.87 ± 1.40^a	0.11 ± 0.05^b	689 ± 26^{ab}

Legend: Abbreviations describe the enrichment method: LP, lemon peel; PP, pomegranate peel; OP, orange peel. Values are presented as the mean ± standard deviation. Different letters in the same column indicate a significant difference ($p < 0.05$).

a decrease in interactions between protein aggregates with the OP particles [9]. Similarly, Sendra *et al.*, [28], found that the addition of a low level (0.2%) of orange fiber to yogurts weakened the structure of yogurt, but the addition of higher amounts (1%) led to the absorption of water and increased the strength of casein network.

Thixotropy increased with the addition of fruit peel (Table 1). Heated LP-enriched yogurt exhibited the highest thixotropy. Similarly, Oroian *et al.*, [29], found that yogurt enriched with cranberry powder presented a higher thixotropy than that of the control yogurt. Espírito-Santo *et al.*, [30], explained the difference between rheological behaviors of control and passion fruit fiber-enriched yogurt by the interaction of pectin with protein. However, these interactions are weaker than protein-protein interactions in yogurt which could lead to more shear sensitivity thus a higher thixotropy. Koksoy and Kilic [17], reported that pectin increased the thixotropy in yogurt drinks by preventing casein aggregation and reducing particle size, and increasing surface charges. Thixotropic yogurts can stay stable and thick without shear during storage while showing a light mouthfeel with applied shear during consumption.

The elastic modulus (G') and the viscous modulus (G") of yogurts are given in Figure 2. All yogurts showed a gel behavior according to the results (G' > G"). The yield stress values are given in Table 2. Yield stress value shows the strength of a gel at which point the gel starts to flow as a viscous liquid. Yoghurt has a three-dimensional protein network with a weak gel structure that can be damaged by shear [31]. Heated OP-enriched yogurt had the highest yield stress among the samples. Similarly, Kieserling *et al.*, [32], found the enrichment of pectin-rich orange fiber increased yield stress in yoghurt. The fiber particles in fruit peels could act as anchors to support and stabilize the casein network. Moreover, the pectin in the peels could also stabilize the casein network by forming bridges. Thus, the resistance of the gel structure to flow and deterioration increases.

Table 2. Yield stress of yogurt samples

Parameters	Yield stress (Pa)
Control	0.90 ± 0.00[ab]
LP	0.84 ± 0.05[ab]
Heated LP	0.90 ± 0.14[ab]
PP	0.62 ± 0.09[b]
Heated PP	0.88 ± 0.02[ab]
OP	1.15 ± 0.07[a]
Heated OP	1.35 ± 0.28[a]

Legend: Abbreviations describe the enrichment method: LP, lemon peel; PP, pomegranate peel; OP, orange peel. Values are presented as the mean ± standard deviation. Different letters in the same column indicate a significant difference ($p < 0.05$).

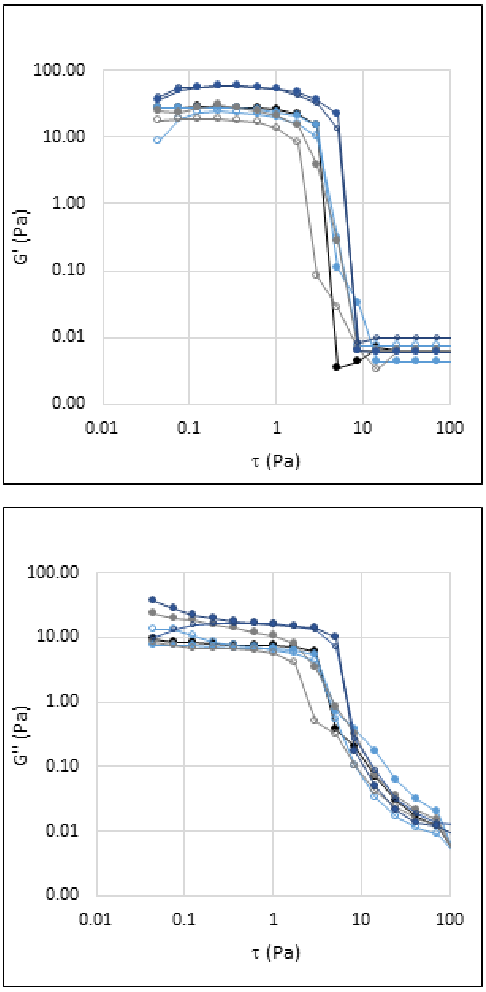

Figure 2. Elastic (G') and viscous modulus (G") of yogurt samples: (•) control; (°) lemon peel; (•) heated lemon peel; (°) pomegranate peel; (•) heated pomegranate peel; (°) orange peel; (•) heated orange peel

4. Conclusions

- The addition of fruit peel powder solutions of lemon, pomegranate, and orange was found to affect the quality of yogurt. Heated orange and lemon peels had a higher impact on the physical properties of yogurt than pomegranate peel.
- Yoghurt enriched with heated lemon peel resulted in the highest water-holding capacity and apparent viscosity.
- Yoghurts enriched with heated orange peel and lemon peel had the highest consistency coefficient and thixotropy.
- The yield stress of the yogurt enriched with heated orange peel was found to be the highest. These effects can be related to polysaccharide content, especially pectin in the peels.
- Heat treatment can increase the pectin solubility resulting in more effect on the physical properties of yoghurt. Hence, fruit peels as a source of dietary fiber can be utilized as a functional ingredient to improve

yoghurt quality and functionality by the food industry.
- In addition, food waste containing health-improving compounds can be utilized in this way.

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