Original Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.39121

Pear pomace powder added quinoa-based gluten-free cake formulations: effect on pasting properties, rheology, and product quality

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Abstract

Pear pomace powder (PPP), xanthan gum (XG), and their combined effect on batter rheology, pasting properties, and the quality parameters of quinoa-based gluten-free cupcakes (GFC) were investigated. The water-retention capacities of flour blends, the batters' rheological properties, and the flour blends' pasting properties were analyzed and the quality characteristics of the GFCs were determined. The addition of XG to the formulation led to an increase in peak viscosity, final viscosity, and breakdown viscosity while PPP content caused a decrease. Opposite effects that XG and PPP have on pasting properties help to form a more stable structure. PPP and XG demonstrated escalating impacts on the flour blends' water-retention capacities, density, and batter viscosity. All batters displayed pseudoplastic behavior, whereas Power-law model was found to be the most suitable model describing the batter's rheological characteristics. Increasing PPP and/or XG amounts led to larger elastic and viscous modulus. The PPP addition decreased the cake volumes and increased the crumb hardness. However, the XG addition to the blends caused the sample volume to increase and the hardness to decrease. The porosity of the samples decreased as the amount of PPP increased in the formulation. However, in the presence of XG, PPP demonstrated increased porosity.

Keywords: gluten-free; pear pomace; pasting properties; food rheology; cake quality.

Practical Application: Pear pomace powder and xanthan gum were used to improve nutritional and product quality.

1 Introduction

Celiac disease is an autoimmune enteropathy that triggers lifelong gluten intolerance. Gluten is a therapeutic term that describes the ethanol-soluble proteins of wheat, rye, barley, and their cross-bred crops. A lifelong gluten-free diet is the only medical option for celiac patients, and it includes the consumption of fresh fruit, vegetables, seafood, meat, poultry, legumes, nuts, and most dairy products. There is currently a wide range of gluten-free alternatives to conventional gluten-containing foods, such as bakery items that use gluten-free cereals and pseudocereals as their base ingredients, rice, corn, quinoa, and amaranth (Malalgoda et al., 2018). However, gluten-free products are commonly associated with low technological quality properties, rapid staleness, low protein and mineral content, and higher amounts of carbohydrates and fat than recommended (Graça et al., 2020).

Quinoa (*Chenopodium quinoa* Willd.) is a pseudo-cereal with high-quality protein, polyunsaturated fatty acids, minerals, dietary fibers, and polyphenols. The high nutritional value of quinoa makes it a viable alternative for celiac disease patients and quinoa may be helpful for type 2 diabetes, cancer, obesity, and dyslipidemia (Navruz-Varli & Sanlier, 2016). Because of these biological benefits and rich nutrients, the usage of quinoa flour in gluten-free bakery products such as bread, muffin, pasta, and cake can be a promising alternative (Villa et al., 2020; Franco et al., 2021; Aprodu & Banu, 2021; Torres Vargas et al., 2021; Mousa, 2021).

XG is a water-soluble extracellular heteropolysaccharide that provides good rheological properties that lead to improving smoothness, air incorporation, and retention, recipe tolerance, stability, and product texture of the food matrix. XG is also preferred because of its' non-toxicity, biodegradability, and low cost (Sworn, 2021).

Fruit and vegetable by-products serve as cost-effective sources of functional ingredients, such as vitamins, enzymes, and especially dietary fibers (DFs). DFs from plant materials are increasingly being incorporated into various food products because of their functional properties, including water-holding, gel-forming, fat mimetic, texturizing, and thickening properties that enhance the texture, sensory qualities, and shelf-life of foods. Furthermore, DFs may have beneficial biological properties, such as improving colon health, lowering the risk of chronic diseases, and shielding cells from oxidative damage (Grigelmo-Miguel & Martín-Belloso, 1999). These positive effects have led to investigations of fruit and vegetable by-products such as pulp, pomace, cladodes, stem, peel, pomace skin, sheets, and bagasse, etc. (Rufino et al., 2011; Sudha et al., 2007; Ayadi et al., 2009; Bensadón et al., 2010; Al-Sayed & Ahmed, 2013; Deng et al., 2011; Atef et al., 2013; Sangnark & Noomhorm, 2004; Rocha-Parra et al., 2019; Gularte et al., 2012). By adding these by-products, it is

Received 09 June, 2021
Accepted 17 Dec., 2021
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provided enrichment of soluble (SDFs) and insoluble (IDFs) DFs contents, complex polysaccharides, carbohydrates, and vitamins contents (Campos et al., 2020).

Besides the beneficial biological properties, DFs have functional properties such as water binding, gelling, and structure building which affect the stability of the food during production and storage, production parameters, and texture and volume of the final product (Jeddou et al., 2017; Mudgil et al., 2017; Lebesi & Tzia, 2011).

Pear pomace (PP) has been found to contain useful substances, such as phenolic compounds and organic acids, in addition to DFs. Therefore, PPP has been investigated as a fiber source. The IDFs isolated from PP were found to enhance intestinal microbiota, preventing obesity in rats that follow high-lipid diets (Rocha-Parra et al., 2019). Thus, PPP has a great potential to use as a food enrichment ingredient that helps to improve both beneficial biological properties for humans, and quality parameters of foods.

PPP is a good alternative product for antiobesity and glucose homeostasis improvement because of its' high dietary fiber content (Chang et al., 2017) and it was studied in wheat flour-based layer cake production as a dietary fiber enrichment tool. However, there are no studies about the utilization of PPP in the gluten-free cake formulation as a functional ingredient to the authors' knowledge. This study aims to investigate the effects of usage of PPP and/or XG on batter rheology, flour blends' pasting properties, and cake quality in a quinoa-based GFC formulation and to produce functional and highly nutritional cupcakes.

2 Materials and Methods

2.1 Materials

The ingredients used for preparing GFC include white quinoa flour (*Chenopodium quinoa* Willd.) (Bora Tar. Ür. Gıda San. ve Tic. Ltd. Şti., Istanbul, Turkey), rice flour (Kenton, Ankara, Turkey), potato starch (Başak Gıda Dağıtım Pazarlama San. Tic. A.Ş., Istanbul), sugar (Konya Şeker San. ve Tic. A.Ş., Konya, Ankara), baking powder (Dr-Oetker Gıda San. ve Tic. A.Ş., Izmir), pasteurized liquid whole eggs (İpay A.Ş., Izmir), icing shortening (Felda Iffco Gıda San. ve Tic. A.Ş., Izmir), and whole milk (fat 3.3% and protein 3%) (Pınar Süt Mamulleri Sanayi A.Ş., Izmir, Turkey) (Bozdogan et al., 2019). Santa Maria pears *(Pyrus communis L.)* purchased from the local market were used to obtain PPP. Ethanol (PubChem CID:702), acetone (PubChem CID:180), and n-hexane (PubChem CID:8058) were supplied by Merck (Darmstadt, Germany). The XG, α-amylase, protease, and amyloglucosidase were purchased from Sigma-Aldrich (St. Louis, USA).

2.2 Methods

Production of Pear Pomace Powder (PPP)

PP is a by-product obtained from juice production. The pomace was extracted by applying washing, coring, and juice extraction using a juice extractor (Santos SA No:50, Lyon, France) to pears. The wet pomace was washed twice with a mixture of 1% ascorbic-citric acid (1:1) to eliminate potential spoilage microorganisms (30 °C) (Larrauri, 1999) and rinsed twice with warm water (30 °C) and then dried at 65 °C in a tray drier (Armfield Ltd., Ringwood Hampshire, England) until it reached a moisture level of 4.9% approximately 10 h. Dried pomace was ground to a fine powder (≤ 280 μm) using a hammer mill (Armfield, UK).

Preparation of gluten-free cupcakes

GFC formulations (Table 1a) and preparation were conducted following Bozdogan et al. (2019). Cake formulation containing 50% quinoa was chosen as the control and PPP (0, 4, 8, 12%), and/or XG (0, 0.5, 1%) were added to the formulation in different amounts to replace a mixture of quinoa flour (protein 13.72%, fat 6.84%, ash 2.45%, total dietary fiber (TDF) 16.27%), rice flour (protein 6.87%, fat 1.41%, ash 0.40%, TDF 7.91%), and potato starch (protein not detected, fat 0.29%, ash 0.24%, TDF 0.80%). The pasteurized whole egg was whisked for 4 min at 10 by using Kitchen-Aid Professional mixer (Kitchen Aid K45 Mixer, St. Joseph, MI, USA). Sugar was mixed with whisked egg at speed 10 (3 min.) and then milk and shortening were added and mixed

Table 1a. The compositions of the gluten-free cakes enriched with PPP and/or XG.

Ingredients (g)	Formulations of the Gluten-Free Cupcakes											
	Control	4% PPP	8% PPP	12% PPP	0.5% XG	0.5% XG +4% PPP	0.5% X.G + 8%PPP	0.5% XG + 12% PPP	1% XG	1% XG + 4%PPP	1% XG + 8%PPP	1% XG + 12%PPP
Rice Flour	25	24	23	22	24.875	23.5	22.875	21.875	24.75	23.75	22.75	21.75
Potato Starch	25	24	23	22	24.875	23.875	22.875	21.875	24.75	23.75	22.75	21.75
Quinoa Flour	50	48	46	44	49.75	47.75	45.75	43.75	49.5	47.5	45.5	43.5
PPP	—	4	8	12	—	4	8	12	—	4	8	12
Xanthan Gum	—	—	—	—	0.5	0.5	0.5	0.5	1	1	1	1
Whole Egg	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
Milk	75	75	75	75	75	75	75	75	75	75	75	75
Sugar	57.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5
Shortening	36.25	36.25	36.25	36.25	36.25	36.25	36.25	36.25	36.25	36.25	36.25	36.25
Baking Powder	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75

at speed 4 (4 min). At the final step powder mix (baking powder, flour mix, and PPP and/or XG) were added and blended for one more minute at speed 2. The batter was placed into silicon cake molds after dividing it into 60 g portions. Baking was performed for 30 min at 170 °C in a convection oven (Vestel, Turkey). The baked cakes were removed from the molds and left for cooling at room temperature for 1 h. All formulations contain the same amount of egg, milk, sugar, shortening, and baking powder.

PPP and XG addition percentages were determined according to the results of the preliminary trials where consistency of the batters and texture, volume, sensorial properties (appearance, taste, etc.) of the final product were evaluated.

Chemical composition of PPP

The moisture content and TDF, SDF, and IDF contents of PPP were analyzed according to methods no 920.151 and 991.43, respectively (Association of Official Analytical Chemist, 1998). The ash (08-01), fat (30-20), and protein (46-30) (Nx6.25) contents of PPP were determined according to the American Association of Cereal Chemists (2000).

Water-retention capacity (WRC)

The WRC of PPP, flour and dry matter (dm) blends were measured according to method no 56-11 (American Association of Cereal Chemists, 2000).

Pasting properties

The pasting properties of flour blends were determined with a stress-controlled rheometer (TA DHR3, TA Instruments Inc., New Castle, DE, USA) using a starch pasting cell based on the procedure reported by Tiga et al. (2021). Sample slurries were prepared by dispersing 2.5 g of sample in distilled water until the total weight of the slurry reached 25 g. Samples were analyzed immediately after preparation. At least three measurements were recorded for each sample.

The peak viscosity (PV), trough viscosity, breakdown viscosity (BV), final viscosity (FV), setback viscosity (SB), peak time (PeT), and pasting temperature (PaT) of the samples were determined.

The density of cake batters

The batter density measurements were conducted using a pycnometer (Elcometer 1800, Manchester, UK), which is a cup comprising a 100 mL cylindrical container.

Rheological properties of cake batters

The batters were analyzed for flow and oscillatory properties using a stress-controlled rheometer (DHR- 3, TA Instruments, New Castle, DE, USA). Parallel plate geometry with a 40 mm diameter was used with a 1 mm gap. Flow ramp test, strain sweep test, and frequency sweep test were conducted on each batter (25 ± 0.1 °C).

The flow properties were determined at a shear rate between 0.01 and 100 s^{-1} under steady shear conditions. Shear stress vs shear rate data were fitted into the Power-law (Equation 1), the Herschel–Bulkley (Equation 2), and the Casson models (Equation 3):

$$\sigma_{yz} = K.\dot{\gamma}_{yz}^{n} \tag{1}$$

$$\sigma_{yz} = \sigma_0 + K.\dot{\gamma}_{yz}^{n} \tag{2}$$

$$\sigma_{yz}{}^{0.5} = \sigma_{0C}^{0.5} + K_c^{0.5}.\dot{\gamma}_{yz}^{0.5} \tag{3}$$

where K is the consistency index (Pa s^n), n is the flow behavior index, σ_{yz} is the shear stress (Pa), σ_0 is the yield stress (Pa), and $\dot{\gamma}_{yz}$ is the shear rate (1/s).

Frequency sweep tests were performed at a strain of 0.04% and at frequencies between 0.01 and 10 Hz to investigate the viscoelastic properties of the batters in the linear viscoelastic region that was determined using strain sweep tests. The storage modulus (G′), loss modulus (G″), and loss tangent (tanδ) were recorded as a function of frequency.

Physicochemical analysis of gluten-free cupcakes

The moisture (44-15A), ash (08-01), fat (30-25), and protein (Nx6.25) (46-30) contents of the GFCs were analyzed according to the American Association of Cereal Chemists (2000).

Physical properties of cakes

The specific volume of the cakes was determined based on method 72-10 (American Association of Cereal Chemists, 2000). The surface and crumb color of GFCs were measured using a colorimeter (Hunter Associates Inc., Reston, VA, USA). The texture properties of the cake crumbs were determined by a TA-XT2 texture analyzer (Stable Micro System Co. Ltd., Surrey, England). Details of test parameters and the probe used were given in Bozdogan et al. (2019).

Microstructure of cakes

Scanning Electron Microscopy (SEM) measurements helped determine the microstructure of rice flour, quinoa flour, PPP, and GFCs. Before the measurements, cake samples were cut into small particles and freeze-dried (Armfield, 158 FT 33, England) at −18 °C. It was performed using a Quanto 250 FEG SEM (FEI Inc., Hillsboro, Oregon, USA) after coating all samples with gold (Emitech K550×, France).

Sensory analysis

The sensory evaluation of GFCs was conducted following Jeddou et al. (2017) by 20 semi-trained panelists all of the panelists were recruited among the staff and graduate students of Ege University Food Engineering Department, between the age of 20–60 years (16 women and 4 men). A five-point hedonic scale test was followed. Samples were assessed in terms of crumb color, texture, general appearance, flavor, and overall liking based on a five-point hedonic scale in which "dislike extremely" was scored as 1and "like extremely" as 5.

Data analysis and optimization

The optimization of the PPP and XG usage was conducted by the Design Expert 7.0.0 software (Stat-Ease Inc., Minneapolis, MN, USA) using the RSM. The desirability function method was conducted to optimization of the independent variables, which were chosen as A: XG, and B: PPP; while the specific volume, K, overall liking, PV, BV, and SB, were evaluated as responses.

One-way ANOVA was used to carry out statistical analysis on the results for comparison (α=0.05). In case of a significant difference, the means of the results were compared using Duncan multiple comparison tests (α=0.05) (IBM SPSS Statistics 20; IBM, Chicago, IL).

The variables, specific volume, PV, BV, SB, K (Power-law), and crumb hardness, were analyzed employing principal component analysis (PCA) and to identify any associations between groups, Hierarchical Clustering on Principal Components (HCPC) was conducted (SIMCA Software, 14.1 Trial Version, Umetrics, Sweden). The distribution of GFCs into the groups was determined by Euclidean distance dissimilarities and clustering and calculated by Ward's method.

3 Results and discussion

3.1 Chemical composition of PPP

The TDF amount of PPP was found to be 78.93 ± 0.14% and the SDF and IDF contents of the PPP were determined as 22.922% and 77.078% of the TDF, respectively. Results showed that PPP (78.93 ± 0.14%) has a much higher amount of TDF than that of quinoa flour (16.27 ± 0.48%), rice flour (7.91 ± 1.50%), and potato starch (0.80 ± 0.01%). Because of the high amount of SDF and IDF of PPP, it can be considered to use as a promising source to enrich GFC in terms of DFs (O'Shea et al., 2012; Martínez et al., 2012; Negi et al., 2021; Mateos-Aparicio, 2021). More than 20% of celiac disease patients have at least a nutritional deficiency, such as in calories, DFs, vitamins, and minerals because of small intestine abnormalities (Theethira et al., 2014). Furthermore, studies showed that consumption of DFs has positive effects on diabetes, cholesterol, hypertriglyceridemia, obesity, hypertension, cardiovascular disease, and colon cancer (Chen et al., 2018; Fujii et al., 2013; O'Keefe, 2019; Chaouch & Benvenuti, 2020; Fuller et al., 2016).

Therefore, investigating the sidestream products, such as PPP, as an alternative enrichment ingredient in gluten-free products is important to improve the living standards of patients who suffer from celiac disease.

Martin-Cabrejas et al. (1995), and Rocha-Parra et al. (2019) have used PPP as a DFs source which has 43.9%, and 66.55% DFs content respectively. The PPP used in this study has a DFs content similar to that reported by Rocha-Parra et al. (2019). The DFs content depends on the growing conditions, the pre-treatment methods, and the production processes. In this study, the IDF fraction prevails in PPP and Martin-Cabrejas et al. (1995) reported similar results. However, the SDF content of the PPP was found to be high compared to other studies.

The moisture content of PPP was found to be 4.90 ± 0.06%, lying in the range of suggested moisture levels for commercial DFs by Larrauri (1999). The protein, oil, and ash contents of the PPP were determined as 2.89 ± 0.06%, 1.88 ± 0.15%, and 1.20 ± 0.06%, respectively, which were found to be compatible with those reported by Grigelmo-Miguel & Martín-Belloso (1999).

3.2 Water-retention capacity

The WRC is an important functional property that affects the final structure and finished-product quality (Shevkani et al., 2014). The WRCs of rice flour, quinoa flour, potato starch, and PPP were found to be 1.18 ± 0.21, 1.20 ± 0.22, 0.62 ± 0.21, and 3.48 ± 0.11 g water/g dm, respectively. Due to their good hydration properties, DFs improve the structural properties of foods by increasing their viscosity. Rocha-Parra et al. (2019) reported similar results for the water-binding capacity of the PPP.

The WRCs of the dry matter blends ranged between 0.9052-1.5354 g water/g dm (Table 1b). Increasing the amount of both PPP and XG caused an increase while XG was found to be more effective in terms of WRC due to its quick hydration characteristic. The reason is although both XG and PPP are DF, XG contains only SDF while PPP contains both SDF and IDF and IDF prevails in PPP. However, both PPP and XG facilitated water retention and are expected to produce highly viscous batters.

3.3 Pasting properties of flour blends

The pasting properties PaT, PV, BV, and SB of quinoa flour, rice flour, potato starch, and their blends that enriched with PPP and/or XG are given in Table 1c and the pasting curves are illustrated in Figure 1a. The PaT of the materials, which indicates the minimum temperature required for gelatinization, was found to change between 59.7–84.9 °C. The lowest and highest PaT were determined for potato starch and rice flour, respectively. Tiga et al. (2021) reported similar PaT for potato starch. Dang & Copeland (2004) determined different PaT for rice flour ranging between 76.8-83.1 °C and stated that the growing season and location of rice are effective parameters on pasting temperature. The PaT of the quinoa flour that was used in the study was found as 74.34 °C, which is similar to the results that were given by Li and Zhu (2017). The increasing concentration of PPP led to a significant ($p < 0.05$) increase in PaT while XG caused a significant ($p < 0.05$) decrease. Increasing pasting temperature would be caused by the delayed or restricted swelling and amylose leaching (Mira et al., 2005). In PPP enriched formulations less starch granules that form the paste and lower protein content that plays an important role to initialize pasting would be the reasons for temperature delay (Collar et al., 2006). In addition, the high WRC of the PPP would be another reason since less available water would delay the swelling of starch granules during the heating process (Sudha et al., 2007). Sudha et al. (2007) found that increasing apple pomace was caused to an increase in the PaT of the blends and stated that the difference in PaT may be impacted by the different gelation temperatures of the DF fractions PPP contains. Decreasing in the PaT caused by the increase in XG concentration may be resulted from the ion bridging of the opposite charges of flour blends which can be caused by cationic groups of quinoa proteins that can be ionized

Table 1b. WRC of the flour blends, the density of the batters and flow behaviors of the batters.

Sample	WRC (g water/ g dry matter)	Density (g/cm^3)	Power Law Model			Herschel–Bulkley				Casson Model		
			n_p	K_{cp} (Pa.s^n)	R^2	σ_0	K	n	R^2	σ_0	K	R^2
Control	0.9052 ± 0.2^{a}	0.84 ± 0.02^{bc}	0.343 ± 0.003	18.541 ± 0.227	0.994	0	18.628 ± 1.323	0.342 ± 0.011	0.994	28.532 ± 0.660	0.169 ± 0.005	0.938
4% PPP	0.9964 ± 0.21^{ab}	0.84 ± 0.00^{ab}	0.387 ± 0.002	23.942 ± 0.232	0.997	7.779 ± 1.695	19.489 ± 0.943	0.419 ± 0.008	0.997	38.347 ± 0.548	0.322 ± 0.005	0.983
8% PPP	1.0855 ± 0.22^{abc}	0.84 ± 0.00^{ab}	0.379 ± 0.002	31.887 ± 0.336	0.996	21.767 ± 1.921	19.732 ± 0.977	0.455 ± 0.008	0.997	50.746 ± 0.609	0.402 ± 0.006	0.987
12% PPP	1.2035 ± 0.21^{abc}	0.84 ± 0.00^{bc}	0.392 ± 0.003	38.799 ± 0.444	0.996	32.818 ± 2.274	21.436 ± 1.060	0.488 ± 0.008	0.997	62.610 ± 0.713	0.547 ± 0.007	0.989
0.5% XG	0.8938 ± 0.28^{a}	0.83 ± 0.00^{a}	0.374 ± 0.003	59.952 ± 0.728	0.995	61.601 ± 3.033	26.874 ± 1.355	0.504 ± 0.009	0.997	95.309 ± 0.935	0.722 ± 0.009	0.991
0.5% XG + 4% PPP	1.2079 ± 0.24^{abc}	0.84 ± 0.00^{ab}	0.388 ± 0.003	77.586 ± 1.127	0.993	103.428 ± 3.599	26.361 ± 1.350	0.566 ± 0.009	0.997	125.352 ± 1.080	1.046 ± 0.011	0.993
0.5% XG + 8% PPP	1.3013 ± 0.21^{abc}	0.85 ± 0.00^{cd}	0.279 ± 0.004	141.759 ± 2.564	0.978	206.164 ± 5.993	18.961 ± 2.020	0.603 ± 0.019	0.989	201.942 ± 1.889	0.703 ± 0.012	0.980
0.5% XG + 12% PPP	1.4359 ± 0.05^{bc}	0.86 ± 0.00^{d}	0.092 ± 0.007	279.734 ± 8.476	0.659	0	279.687 ± 341.013	0.093 ± 0.087	0.658	337.922 ± 8.222	0.047 ± 0.011	0.211
1% XG	1.0067 ± 0.17^{ab}	0.85 ± 0.01^{bc}	0.262 ± 0.004	133.882 ± 2.303	0.955	177.740 ± 6.253	21.075 ± 2.439	0.553 ± 0.020	0.986	186.254 ± 1.830	0.559 ± 0.011	0.975
1% XG + 4% PPP	1.2153 ± 0.24^{abc}	0.85 ± 0.00^{cd}	0.473 ± 0.003	65.196 ± 0.970	0.991	100.070 ± 3.179	25.690 ± 0.981	0.632 ± 0.007	0.999	112.839 ± 0.989	1.752 ± 0.013	0.997
1% XG + 8% PPP	1.2964 ± 0.14^{abc}	0.87 ± 0.00^{e}	0.319 ± 0.002	173.692 ± 1.921	0.988	161.924 ± 8.162	74.260 ± 4.188	0.452 ± 0.009	0.993	260.919 ± 2.420	1.272 ± 0.018	0.987
1% XG + 12% PPP	1.5354 ± 0.22^{c}	0.91 ± 0.00^{f}	0.436 ± 0.005	185.083 ± 4.298	0.975	383.467 ± 11.442	34.593 ± 2.618	0.728 ± 0.014	0.991	312.691 ± 3.631	3.741 ± 0.042	0.992

Table 1c. Pasting properties of the flour blends.

Sample	Pasting Temperature (°C)	Peak Time (s)	Peak Viscosity (cP)	Through Viscosity (cP)	Final Viscosity (cP)	Breakdown Viscosity (cP)	Setback Viscosity (cP)
Quinoa	74.340 ± 0.098^{b}	529.788 ± 0.515^{b}	154.47 ± 3.76^{a}	249.64 ± 3.79^{a}	381.74 ± 6.51^{a}	95.17 ± 0.03^{a}	132.10 ± 2.72^{a}
Potato starch	59.73 ± 0.560^{a}	275.141 ± 9.902^{a}	5956.375 ± 329.31^{c}	1486.59 ± 26.83^{c}	2004.55 ± 29.29^{c}	4469.79 ± 302.48^{c}	517.96 ± 2.46^{b}
Rice flour	84.886 ± 0.123^{c}	566.605 ± 1.139^{b}	2495.41 ± 54.56^{b}	1009.76 ± 12.23^{b}	1596.83 ± 15.84^{b}	1485.64 ± 42.76^{b}	587.06 ± 3.62^{c}
Control	64.845 ± 0.148^{ef}	543.641 ± 0.727^{d}	1113.97 ± 17.71 ^{de}	677.13 ± 5.94^{cd}	1008.16 ± 7.63^{cd}	436.84 ± 11.77^{efg}	331.02 ± 0.002^{h}
4% PPP	64.776 ± 0.257^{e}	537.803 ± 2.066^{bc}	1027.47 ± 28.96^{cd}	657.28 ± 7.70^{bcd}	955.48 ± 13.22^{bc}	370.20 ± 21.34^{cde}	298.20 ± 5.91^{ef}
8% PPP	64.783 ± 0.065^{e}	540.814 ± 1.165^{cd}	888.78 ± 27.86^{ab}	615.68 ± 12.36^{ab}	872.49 ± 16.06^{a}	273.10 ± 15.52^{b}	256.81 ± 3.71^{cd}
12% PPP	65.150 ± 0.183^{f}	539.299 ± 3.083^{bcd}	783.80 ± 11.27^{a}	588.91 ± 4.17^{a}	814.08 ± 2.32^{a}	194.89 ± 7.10^{a}	225.17 ± 1.85^{a}
0.5% XG	63.876 ± 0.188^{d}	536.466 ± 1.529^{bc}	1272.34 ± 25.14^{fgh}	746.65 ± 7.87^{efg}	1093.72 ± 5.99^{ef}	525.68 ± 17.32^{hi}	347.07 ± 1.92^{i}
0.5% XG + 4% PPP	63.756 ± 0.149^{cd}	534.903 ± 3.156^{ab}	1204.06 ± 136.63^{efg}	733.62 ± 52.37^{ef}	1043.96 ± 67.94^{de}	470.44 ± 85.32^{fgh}	310.34 ± 15.74^{fg}
0.5% XG + 8% PPP	63.520 ± 0.212^{bc}	535.639 ± 0.707^{b}	1033.14 ± 4.97^{cd}	672.13 ± 8.20^{cd}	935.11 ± 8.13^{b}	361.01 ± 13.17^{cd}	262.99 ± 0.07^{d}
0.5% XG + 12% PPP	63.545 ± 0.021^{bcd}	536.135 ± 2.845^{bc}	920.62 ± 4.98^{bc}	634.05 ± 3.32^{abc}	868.09 ± 6.43^{a}	286.56 ± 8.31^{b}	234.03 ± 3.11^{ab}
1% XG	63.203 ± 0.064^{ab}	534.474 ± 2.884^{ab}	1344.28 ± 33.50^{h}	796.76 ± 13.12^{gh}	1155.22 ± 20.36^{f}	547.53 ± 20.39^{i}	358.46 ± 7.25^{i}
1% XG + 4% PPP	63.120 ± 0.283^{a}	530.288 ± 1.192^{a}	1308.11 ± 127.55^{gh}	807.98 ± 64.35^{h}	1131.86 ± 77.36^{f}	500.13 ± 63.20^{ghi}	323.88 ± 13.01^{gh}
1% XG + 8% PPP	63.205 ± 0.007^{ab}	534.121 ± 4.239^{ab}	1167.39 ± 7.12^{ef}	755.29 ± 4.47^{fg}	1041.21 ± 5.97^{de}	412.10 ± 2.65 ^{def}	285.92 ± 1.50^{e}
1% XG + 12% PPP	63.100 ± 0.071^{a}	534.647 ± 0.707^{ab}	1030.77 ± 12.62^{cd}	699.28 ± 5.82^{de}	942.97 ± 7.21^{bc}	331.49 ± 6.80^{bc}	243.70 ± 1.38^{bc}

Data are expressed as mean values of replicates ± standard deviation. Different letters within the same column indicate significant differences (*$p < 0.05$*) according to Duncan multiple comparison test.

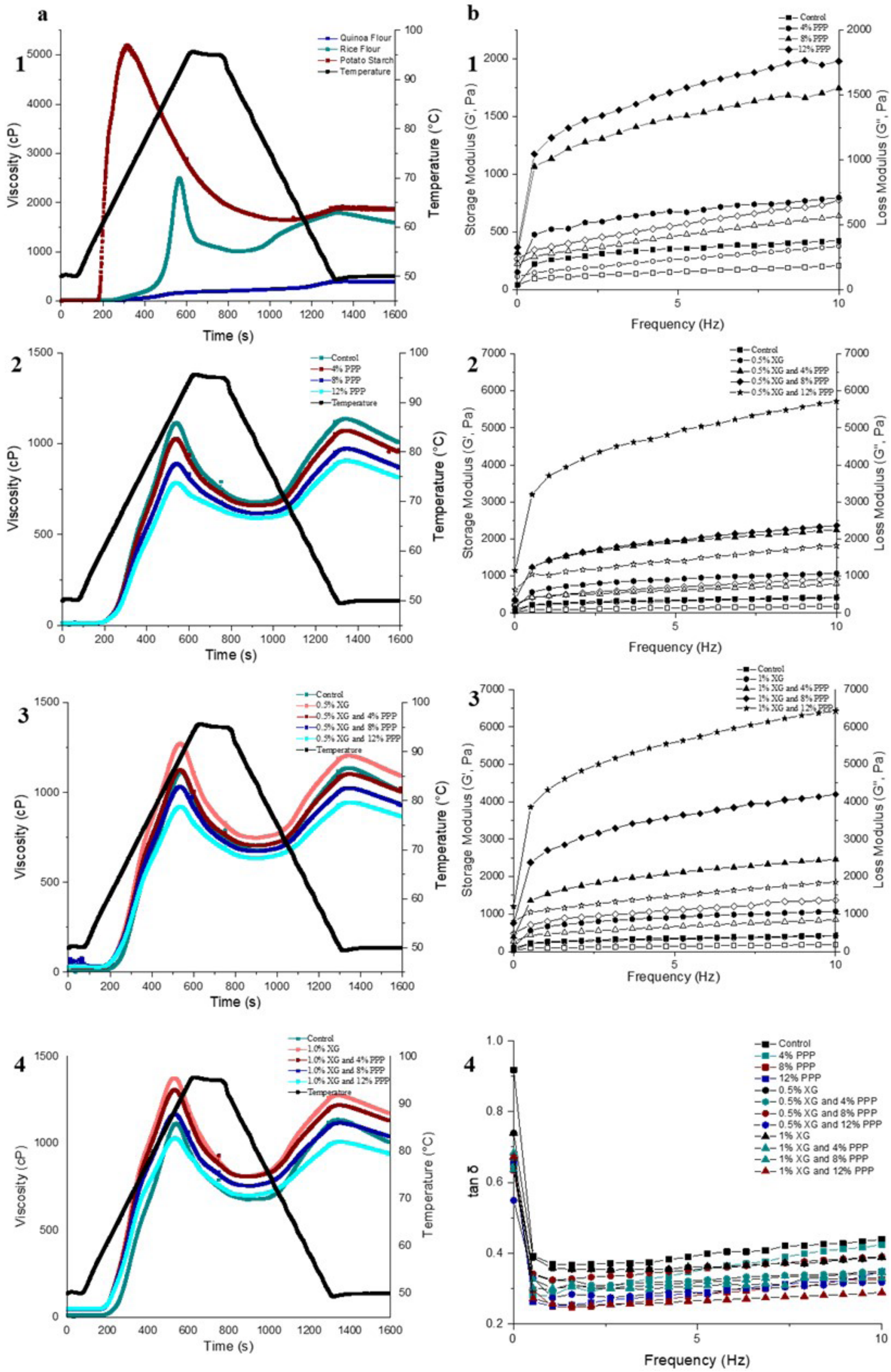

Figure 1. a) Pasting curves of the ingredients and flour blends: 1) pasting curves of PPP, quinoa flour, rice flour and potato starch, 2) pasting curves of the blends that contains only PPP, 3) pasting curves of the blends that contains 0.5% XG and PPP, 4) pasting curves of the blends that contains 1% XG and PPP. b) The viscoelastic behavior of the cake batters: 1) Storage and loss modulus of the batters that contains only PPP, 2) Storage and loss modulus of the batters that contains 0.5% XG and PPP, 3) Storage and loss modulus of the batters that contains 1% XG and PPP, 4) Damping factors of the batters. (The full markers show Storage modulus while the hollow markers show Loss modulus of the batters).

(Dallagnol et al., 2013) and anionic groups of XG and XG made water access to starch granules easily (Cai et al., 2011). PaT is an important parameter during production since it is an indication of the energy consumed during baking and the required time for the production (Palabiyik et al., 2017).

PeT, in which the viscosity of the material reaches a maximum value, is significantly different for quinoa flour, rice flour, and potato starch. Rice flour reached maximum viscosity in a longer time, whereas potato starch reached maximum viscosity in a shorter time. The addition of XG led to a decrease in the PeT of the samples ($p < 0.05$) where XG helps to induce gelatinization because of its' good water solubility characteristic (Cai et al., 2011) and electrostatic interactions that would be formed between cationic groups of quinoa proteins (Dallagnol et al., 2013) and XG. On the other hand, the addition of PPP has a delaying effect ($p < 0.05$) which would be caused by the less starch content of the formulations and less available water to induce the swelling of starch granules during the pasting (Sudha et al., 2007). Pasting analysis simply mimics the baking process of the product. Thus, viscosity changes throughout the analysis may give useful information about the final product. During heating of the blends in the excess water, starch granules absorb the water and swell as a result of gelatinization. Gelatinization of the starch granules leads to an increase in the viscosity and then a decrease which causes by the breakdown of starch granules at high temperatures. At the cooling step, the viscosity of the paste increases because of the association of flour components (Singh et al., 2016). The highest PV was observed in potato starch caused by the high phosphorus content, quinoa displayed the lowest PV, whereas the PV of the samples changed between 783.80-1344.28 cP. Increasing amounts of XG have an escalating impact, while PPP has a decreasing effect ($p < 0.05$). Similar trends were seen in the FV (a material's ability to form a viscous paste) and SB (a measure of retrogradation tendency or syneresis of flours upon cooling of cooked flour pastes) and BV. The weaker resistance of flour-PPP blends under heating and shear-mixing giving rise to decreased viscosity may be attributed to an increase in non-starch compounds (Bae et al., 2014). The higher BV values at higher concentrations of XG and pomace indicate that the fiber fraction interacted with the starch, making the swollen granules more fragile (Sudha et al., 2007). However, decreasing BV values with the increasing amount of PPP in the presence of XG indicates that PPP helps to form a less fragile structure. The gelatinization of starch granules is mostly responsible for the PV of cereal flour. Increases in PPP content can result in a decrease in starch content, affecting the pasting properties. Furthermore, the high DFs help to bind more water, resulting in less available water for starch and, as a result, decreased swelling, as shown by the low pasting profile and reduced starch granule rupturing (Sudha et al., 2007).

The escalating effect of XG on PV and FV indicates that the XG increased the capacity of starch granules to swell during gelatinization causing an increase in viscosity of the paste. Since, XG has good water solubility characteristics (Cai et al., 2011) and can form electrostatic interactions with the cationic groups of quinoa proteins (Dallagnol et al., 2013). On the other hand, increasing SB, and BV imply that the XG interacted with the starch, making the swollen granules more fragile. PPP has a decreasing effect on PV, FV, SB, and BV where the decreasing effect on the PV and FV would be impacted by increasing content of non-starch content in the formulations, less available water for starch for the swelling phase. However, decreasing SB, and BV values point out the formation of a more stable structure with the increasing amount of PPP. Furthermore, the addition of PPP led to a more stable structure which becomes more fragile with the increasing content of XG. High FV and SB generally indicate the formation of structural supports to the crumb structure during cooling, preventing the sunken center of the cake while high PV and BV related to the decreased structural support by retrograded and gelled starch, leading to the collapse of the structure after baking and during cooling (Choi & Baik, 2014). Enrichment of the formulations using both XG and PPP helps to form a more stable structure that prevents the cake crumb from collapsing.

3.4 Density of batters

PPP or XG has no significant effect on the batter's density individually ($p > 0.05$) while the XG and PPP addition together caused the batter density to increase ($p < 0.05$) (Table 1b). The highest density was obtained from the batter prepared with 1% XG and 12% PPP. The batter density demonstrates the air incorporation during mixing and is affected by surface tension, viscosity, and the type and speed of mixing. Lower density implies more air incorporation in batters because high-density batters require more energy for incorporating air. Thus, low density is desirable. However, too low density cannot keep the air inside of the batter. Because of this, appropriate density is associated with good air incorporation during mixing and air retention during baking. Rocha-Parra et al. (2019) stated that replacing flour with different amounts of PP does not significantly change the batter densities. Gómez et al. (2007) indicated that the addition of hydrocolloids caused an increase in the density. In our study, the addition of XG and PPP together caused the density to increase because of the increasing content of both SDF and IDF that leads to improvement in specific volume, porosity, texture, and the microstructure of the final product.

3.5 Rheological properties of gluten-free cupcake batters

Flow behaviors of batters

The addition of both PPP and XG caused an increase in the viscosity and shear stress which were induced by the high WRCs of PPP and XG (Table 1b). Non-starchy carbohydrates that are included in the PPP and XG bound more water, leaving less amounts of free water available to facilitate particle movement in enriched batters, and increased viscosity. High viscosity blocks air incorporation into the batter during the mixing process and induces high density because more energy is required for air incorporation.

Shear stress versus shear rate data fitted fairly well to the Power-law model (Table 1b). The K is important because it highly affects the texture of an aerated baked product which are important factors in consumer preferences. Air incorporation and retention in the matrix, air bubble stability, and the generation of heat convection currents in the batter during baking depend on the initial viscosity and the evolution of bulk viscosity during baking. Low-consistency batters cannot retain air during mixing and baking, resulting in low-volume cakes, whereas higher-consistency batters can restrict batter expansion. The K of batters increased as PPP and XG contents increased, led by the creation of more entangled structures in the matrix. These results are consistent with the results of WRC, which also tend to increase with the addition of PPP and XG. The n values of batters ranged from 0.184 to 0.448, which means all samples showed shear-thinning (pseudoplastic) behavior, which means that the viscosity decreases with the increasing shear rate. The n values of the batters have a decreasing trend as XG increases and an increasing trend as PPP incorporation increases. This shows the creation of more complex structures with the increasing XG than PPP. Kırbaş et al. (2019) determined that increasing the incorporation amount of pomace powders improves the consistency of GFC batters and leads to the formation of a more complex batter matrix.

Viscoelastic properties of batters

G′, G″, and tanδ curves of the formulations that were obtained from frequency sweep tests are shown in Figure 1b. To examine the impact of ingredients on the viscoelastic properties of batters, low deformation conditions were used in which the applied stimulus does not disturb or destroy the batter structure.

The moduli increased as the frequency for all batters increased. Increasing PPP and XG induced an increase in G′, and G″ and a decrease in tanδ of the batters. For all formulations, G′ was higher than the G″, providing values of tanδ lower than 1, which indicates a solid elastic-like behavior. High G′ and low G″ generally reflect a more rigid and stiff material whose tanδ is small. This suggests that increased amounts of PPP and/or XG lead to more rigid and stiff batters. An increase in the viscoelasticity of batters could be explained by the WRC of PPP and XG caused by the non-starchy carbohydrates they contain. Kırbaş et al. (2019) and Rocha-Parra et al. (2019) reported pomace powders having an increasing effect on the viscoelastic properties of batters which are consistent with our findings.

3.6 Physicochemical properties of gluten-free cupcakes

Table 2a illustrates the chemical compositions of the GFC. The PPP amount without XG does not affect the moisture content of the samples. However, in the presence of XG, PPP has a decreasing effect on it ($p < 0.05$). On the other hand, XG caused an increase in the moisture content individually ($p < 0.05$). Gómez et al. (2007) investigated the effects of adding HPMC to the GFCs and determined that the moisture loss of gum-added samples was less than the control sample due to the higher water-holding capacity of hydrocolloids. Gularte et al. (2012) found DFs supplementation did not significantly change the moisture of cakes. The oil content of the GFCs varied between 17.30 and 21.05% and the addition of PPP and/or XG doesn't have a significant effect on it ($p > 0.05$). Kırbaş et al. (2019), indicated that different amounts of pomace powders did not affect the oil content of the GFC. In addition, Gularte et al. (2012) stated that the inulin, guar gum, and oat fiber mixtures used did not affect the oil content of the cakes. The amount of protein in the samples varies between 9.50 and 8.71%. The PPP caused a slight decrease in the protein amount in the samples ($p < 0.05$) because the PPP that was used in the formulation instead of the flour mixture contains a lower amount of protein than quinoa flour. However, the addition of XG to the formulation does not affect the protein content of the samples. Since the amount of XG incorporated to the formulation is very low compared to the amount of PPP, the change in the protein content of the cakes is also low.

The ash content of the GFCs varied between 1.40-1.59%. Both PPP and XG led to an increase in the ash content of the GFCs because of their high ash content ($p < 0.05$).

3.7 Physical characteristics of cakes

The specific volume of the samples varied between 1.41-2.07 cm^3/g (Table 2a). The highest specific volume was found to belong to the sample containing 1% XG. In GFC samples without XG, the addition of PPP led to a decrease in specific volume ($p < 0.05$) while XG was found to have an increasing effect. Kırbaş et al. (2019) and Sudha et al. (2007), reported that usage of pomace powders induced a decrease in specific

Table 2a. The physicochemical properties of the gluten-free cakes enriched with PPP and/or XG.

Sample		Moisture (%)	Crude fat (%)	Protein (%)	Ash (%)	Specific volume (cm^3/g)	Porosity
XG (%)	PPP (%, w/w)						
0	0	27.99 ± 1.62^{ab}	21.04 ± 6.87^{a}	9.49 ± 0.08^{e}	1.48 ± 0.02^{bc}	1.55 ± 0.01^{de}	0.13 ± 0.00^{d}
	4	28.79 ± 0.66^{b}	18.72 ± 4.19^{a}	9.50 ± 0.06^{e}	1.45 ± 0.09^{ab}	1.48 ± 0.01^{bc}	0.17 ± 0.01^{e}
	8	26.17 ± 4.14^{a}	18.07 ± 3.93^{a}	9.04 ± 0.20^{bc}	1.40 ± 0.01^{a}	1.45 ± 0.03^{abc}	0.13 ± 0.01^{d}
	12	27.85 ± 0.65^{ab}	18.28 ± 4.03^{a}	8.71 ± 0.24^{a}	1.47 ± 0.05^{abc}	1.41 ± 0.01^{a}	0.05 ± 0.01^{a}
0.5	0	30.76 ± 0.89^{c}	17.30 ± 4.18^{a}	9.46 ± 0.05^{e}	1.52 ± 0.01^{bcd}	1.59 ± 0.02^{def}	0.04 ± 0.01^{a}
	4	29.16 ± 1.25^{bc}	18.36 ± 4.44^{a}	9.31 ± 0.02^{de}	1.47 ± 0.01^{abc}	1.56 ± 0.02^{def}	0.07 ± 0.01^{ab}
	8	28.56 ± 0.90^{b}	18.56 ± 4.28^{a}	9.09 ± 0.06^{bcd}	1.49 ± 0.01^{bc}	1.54 ± 0.01^{d}	0.10 ± 0.01^{cd}
	12	27.53 ± 0.71^{ab}	18.90 ± 3.80^{a}	8.95 ± 0.080^{ab}	1.55 ± 0.01^{cd}	1.43 ± 0.01^{ab}	0.27 ± 0.01^{f}
1	0	30.65 ± 0.84^{c}	19.83 ± 5.84^{a}	9.41 ± 0.14^{e}	1.55 ± 0.01^{cd}	1.64 ± 0.01^{g}	0.06 ± 0.01^{ab}
	4	27.99 ± 0.68^{ab}	18.68 ± 4.98^{a}	9.35 ± 0.12^{de}	1.55 ± 0.01^{cd}	1.60 ± 0.04^{fg}	0.08 ± 0.02^{bc}
	8	28.57 ± 1.04^{b}	19.56 ± 4.62^{a}	9.25 ± 0.01^{cde}	1.55 ± 0.01^{cd}	1.59 ± 0.01^{ef}	0.19 ± 0.01^{e}
	12	28.19 ± 1.68^{b}	21.05 ± 6.54^{a}	9.23 ± 0.00^{cde}	1.59 ± 0.05^{d}	1.48 ± 0.03^{c}	0.26 ± 0.01^{f}

volume. Gómez et al. (2007) investigated the effects of different hydrocolloids on cake quality, revealing that the specific volume increased by adding hydrocolloids such as in the current study. Density, the batter's viscosity, and the change of viscosity during heating are the main factors that affect the specific volume since they determine the air incorporation during mixing and the capability of the batters to keep the air in the matrix. Both XG and PPP have increasing effects on density and viscosity. However, pasting properties results especially PV, FV, SB, and BV, and results from specific volume analysis indicate that, the formulations enriched with both XG and PPP have a more stable structure which helps to slow down the rate of CO_2 diffusion, and consequently, allowed for improved retention during the early stage of baking. Thus, combining the use of PPP and XG helps produce cakes with a higher specific volume and improved texture (Spotti & Campanella, 2017).

In samples that did not contain XG, the porosity of the GFCs decreased as the amount of PPP increased in the formulation ($p < 0.05$) (Table 2a). However, in the presence of XG, PPP demonstrated increased porosity. The porosity and specific volume of the cakes are more related to the aeration of the batter and air retention capacity of the batter during mixing and baking. A more aerated structure would indicate higher specific volume and a more homogenous porous structure depending on the stability of the structure. Thus, the structure is affected by the WRC and pasting properties of the flour, and the density and viscosity of the batters. Results showed that usage of XG and PPP together helps to form a properly aerated structure with favorable porosity. Lebesi & Tzia (2011) examined how various DFs and edible grain bran affect the quality characteristics of cakes. Results showed that when rice bran, one of the products used as cereal bran, was added to the GFC's at a rate of 30%, the porosity value of the sample was lower than the porosity value of the control.

L*, a*, b*, and ΔE values of the samples' crust and crumb colors were determined (Table 2b). The usage of PPP led to a decrease in the L* and b* values of cake crust, while a* values increased ($p < 0.05$). The increase in the red component of the crust of the cake was caused by the color of the PPP. The crumb of the cakes become darker ($p < 0.05$) as the amount of PPP in the formulations increased. The a* values of the crumb and the crust of the cake were all positive, which means that there was a red hue for crumb and crust which was induced by the color of PPP. The decreasing L* values of both crumb and crust would have resulted from non-enzymatic browning caused by the sugar content of the fiber. In addition, it was determined that the presence of XG increases the effect of PPP in terms of color.

The hardness, springiness, cohesiveness, and resilience of the GFC were analyzed (Table 2b). Hardness tended to increase as the ratio of PPP increased ($p < 0.05$), while decreased with the usage of XG increased ($p < 0.05$). This change in the hardness may be explained by the change in the specific volume of the cakes which is related to the WRC and pasting properties of the flour blends with density and viscosity of the batters. The springiness of the GFC ranged between 0.90-0.95. Increasing the amount of PPP in samples without gum did not affect the springiness of the samples ($p > 0.05$) while XG has an increasing effect on springiness ($p < 0.05$). The cohesiveness increased as the amount of XG increased ($p < 0.05$), which offers information about the recoverability immediately after the first compression. With the increase in the amount of PPP, the cohesiveness of all samples containing gum or not decreased ($p < 0.05$). Kırbaş et al. (2019) examined the effects of pomace powders on GFC samples. The hardness of cakes using the carrot and orange pomace increased as the use of pomace powder increased. In addition, the addition of pomace powder decreased the cohesiveness, springiness, and resilience of the samples. Sabanis & Tzia (2011) found that using hydrocolloids on gluten-free bread and doughs induces a softer structure compared to the control sample.

3.8 Microstructure of cakes

Micrographs at x100 magnified of PPP, quinoa, rice flour, potato starch (Figure 2a) also GFCs (Figure 2b) were used to view the macro and microstructure.

Cake samples that were enriched with both PPP and XG have rougher and irregular structures which increase the WRC due to the high WRC of rough materials with an irregular structure (Aguado, 2010). Therefore, increasing PPP and XG in the formulations led to a decrease in the amount of free water

Table 2b. Texture profile analysis and color analysis of gluten-free cakes enriched with PPP and/or XG.

Sample		TPA				Color Analysis							
						Crumb Color				Crust Color			
XG (%)	PPP (%, w/w)	Hardness (N)	Springiness	Cohesiveness	Resilience	L*	a*	b*	ΔE	L*	a*	b*	ΔE
0	0	31.06 ± 2.24^{ef}	0.93 ± 0.01^{abcde}	0.49 ± 0.02^{bc}	0.24 ± 0.01^{cd}	47.15 ± 0.43^{g}	18.20 ± 0.99^{i}	34.21 ± 0.58^{i}		71.76 ± 0.87^{l}	6.80 ± 1.56^{a}	33.29 ± 0.75^{j}	
	4	31.42 ± 0.84^{cdef}	0.90 ± 0.03^{ab}	0.50 ± 0.01^{bc}	0.24 ± 0.01^{d}	55.89 ± 0.67^{l}	16.73 ± 0.50^{g}	33.78 ± 0.66^{g}	8.90 ± 0.76	67.89 ± 0.60^{i}	9.41 ± 0.67^{j}	31.80 ± 0.43^{i}	4.95 ± 0.71
	8	32.33 ± 2.23^{f}	0.91 ± 0.03^{abc}	0.44 ± 0.01^{a}	0.22 ± 0.01^{b}	53.60 ± 0.07^{k}	17.23 ± 0.12^{h}	33.89 ± 0.50^{h}	6.55 ± 0.05	64.53 ± 0.24^{h}	10.54 ± 0.09^{k}	31.22 ± 0.56^{h}	8.42 ± 0.71
	12	34.05 ± 0.59^{abcd}	0.91 ± 0.02^{abc}	0.44 ± 0.02^{a}	0.21 ± 0.01^{a}	49.26 ± 0.36^{i}	18.64 ± 0.18^{j}	34.39 ± 0.58^{j}	2.25 ± 0.23	61.25 ± 0.26^{g}	10.57 ± 0.05^{l}	30.59 ± 0.05^{g}	11.49 ± 0.23
0.5	0	26.33 ± 4.15^{abc}	0.90 ± 0.03^{a}	0.53 ± 0.02^{de}	0.27 ± 0.02^{e}	49.35 ± 0.47^{j}	19.23 ± 0.14^{k}	35.93 ± 0.26^{l}	2.99 ± 0.45	71.69 ± 0.37^{k}	8.01 ± 0.15^{c}	33.29 ± 0.28^{k}	1.56 ± 0.28
	4	26.91 ± 1.98^{abcd}	0.93 ± 0.04^{abcde}	0.48 ± 0.03^{b}	0.23 ± 0.01^{bc}	42.28 ± 0.40^{d}	15.98 ± 0.09^{f}	16.77 ± 0.29^{e}	18.25 ± 0.35	60.09 ± 0.83^{e}	8.12 ± 0.15^{d}	18.51 ± 0.16^{f}	18.89 ± 0.63
	8	27.30 ± 2.73^{abcd}	0.93 ± 0.02^{abcde}	0.48 ± 0.02^{b}	0.23 ± 0.02^{bc}	43.71 ± 0.54^{f}	15.96 ± 0.13^{d}	17.24 ± 0.09^{f}	17.47 ± 0.11	55.39 ± 0.94^{b}	8.80 ± 0.07^{g}	17.33 ± 0.15^{c}	22.96 ± 0.28
	12	29.68 ± 1.07^{cdef}	0.94 ± 0.01^{bcde}	0.48 ± 0.02^{b}	0.22 ± 0.01^{bc}	41.30 ± 0.18^{c}	15.88 ± 0.07^{c}	16.43 ± 0.14^{d}	18.86 ± 0.18	54.20 ± 0.50^{a}	9.18 ± 0.12^{i}	16.90 ± 0.20^{b}	24.14 ± 0.47
1	0	25.17 ± 2.48^{ab}	0.94 ± 0.02^{cde}	0.54 ± 0.02^{e}	0.27 ± 0.01^{e}	47.74 ± 0.31^{h}	19.38 ± 0.17^{l}	34.89 ± 0.56^{k}	1.57 ± 0.35	71.00 ± 0.14^{j}	8.17 ± 0.06^{e}	34.21 ± 0.15^{l}	1.90 ± 0.08
	4	24.02 ± 2.39^{a}	0.95 ± 0.03^{de}	0.53 ± 0.01^{de}	0.24 ± 0.01^{cd}	40.23 ± 0.13^{a}	15.97 ± 0.10^{e}	15.77 ± 0.15^{a}	19.83 ± 0.14	60.41 ± 0.28^{f}	7.89 ± 0.10^{b}	18.19 ± 0.10^{e}	18.92 ± 0.18
	8	28.13 ± 2.40^{bcde}	0.95 ± 0.03^{e}	0.51 ± 0.02^{cd}	0.24 ± 0.01^{cd}	42.71 ± 0.13^{e}	15.48 ± 0.14^{a}	16.20 ± 0.11^{c}	18.75 ± 0.14	57.78 ± 0.71^{d}	8.64 ± 0.15^{f}	17.54 ± 0.17^{d}	21.15 ± 0.54
	12	29.84 ± 2.84^{def}	0.92 ± 0.02^{abcd}	0.50 ± 0.01^{bc}	0.23 ± 0.01^{bc}	41.00 ± 0.26^{b}	15.74 ± 0.05^{b}	16.11 ± 0.17^{b}	19.28 ± 0.17	55.50 ± 0.27^{c}	9.06 ± 0.15^{h}	16.89 ± 0.09^{b}	23.21 ± 0.27

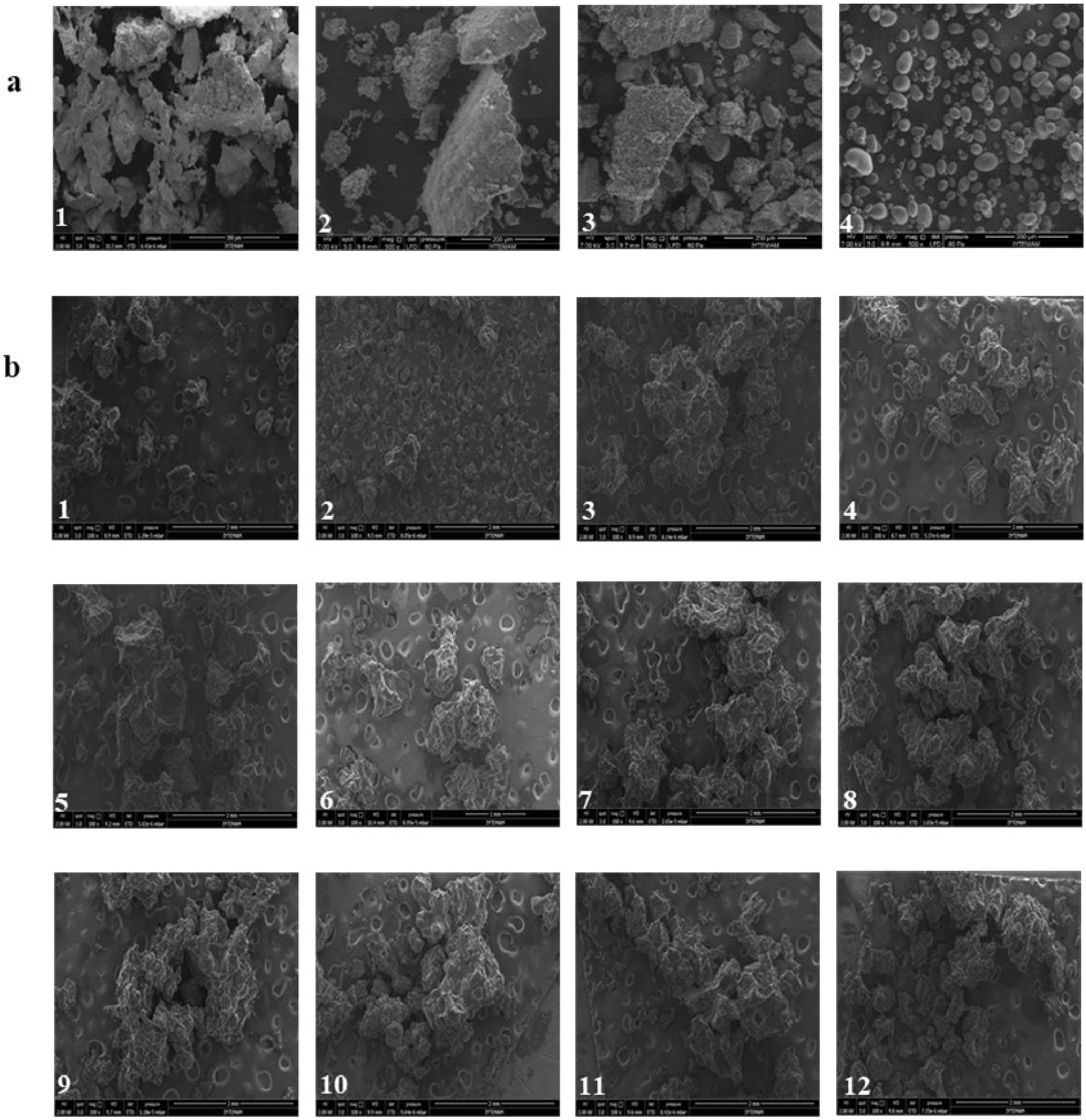

Figure 2. Microstructures of ingredients and gluten-free cupcakes. a) (1) PPP, (2) quinoa flour, (3) rice flour, and (4) potato starch. b) (1) Control, (2) 4% PPP, (3) 8% PPP, (4) 12% PPP, (5) 0.5% XG, (6) 0.5% XG+4% PPP, (7) 0.5% XG+8% PPP, (8)0.5% XG+12% PPP, (9) 1% XG, (10) 1% XG+4% PPP, (11) 1% XG+8% PPP, (12) 1% XG+12% PPP.

which affects the pasting properties, batter viscosity, and batter density. This, in turn, affects the specific volume, porosity, and texture of the products.

The porosity of cakes decreases as the content of PPP increases. XG addition affected the sample microstructure revealing that the cake retained a more continuous structure but started to lose it with increased PPP ratios. As the density increases, air entrance to the structure is prevented together with the XG and PPP, causing the hardness to increase. However, the high viscosity prevents the air inside the structure from escaping.

Turabi et al. (2010) stated that the control cake had small and large pores, its distribution was not homogeneous. Conversely, the cakes containing xanthan-guar gum presented the most uniform and homogeneous pore distribution. Kırbaş et al. (2019) indicated increasing pomace concentration in the formulation caused an increase in non-homogeneity in the structure of the product. Usage of XG and PPP together resulted in the formation of appropriate density and viscosity with a more stable structure which creates appropriate porosity and specific volume.

3.9 Sensory analysis

Sensory analysis results were shown in Table 2c. In terms of color, the highest score belongs to the GFC that did not contain PPP. As the amount of PPP in the samples increased, the color scores and general appearance of the GFC decreased ($p < 0.05$). The samples with higher PPP contents were preferred less by the consumer because of their darker color. The XG addition did not significantly change the color scores and general appearance of the GFCs ($p > 0.05$) (Table 2c). The texture scores of the GFCs decreased by PPP addition ($p > 0.05$) due to the increased hardness while XG addition increased the texture scores ($p < 0.05$)

The use of PPP proved to benefit the flavor of the samples ($p < 0.05$), however, the usage of gum did not cause a significant effect ($p > 0.05$) (Table 2c). The most preferred sample among the produced cakes in terms of taste is the sample containing 1% XG and 4% PPP.

The sample containing 12% PPP for all XG ratios had the lowest score when the overall liking scores were evaluated (Table 2c). In terms of overall liking, the GFC containing 4% PPP for all gum ratios was evaluated with the highest score, but it was observed that the sample using 8% PPP was also evaluated with a very high score.

3.10 Optimization and multivariate statistical analysis

Figure 3 illustrates the interactions of PPP and XG on the responses. As the amount of PPP decreased and the amount of XG increased, the specific volume, PV, BV, and SB values increased. When the amounts of PPP and XG escalated in the formulation, K demonstrated an escalation. Optimization analysis showed that the individual and interaction effects of variables on the responses are significant. Furthermore, desirability analysis showed that the formulation containing 0.5% XG and 8% PPP is the optimum (Table 3).

Multivariate statistical evaluation of the GFCs enriched with PPP and XG on rheological properties of batters, pasting properties of flour blends, physical characteristics, and quality of GFC was performed by PCA and HCPC. Loading and score plots of PCA (R^2:0.99) were given as a biplot (Figure 4). The first principal component (PC1) accounts for 75.7% of the total variability in the data, whereas the second principal component (PC2) accounts for 20.1% and regarding the plot, there were four different groups. Hardness and specific volume clustered on different sides of the loading pilot, meaning that they are negatively correlated. In addition, specific volume and PV, FV, and SB are clustered on the same sides, meaning that they are positively correlated. It should also be noted that all of these values exhibited increasing trends with the addition of XG while decreasing trends with the addition of PPP. The samples enriched with high PPP amounts (8% and 12%) demonstrated high K when XG was added, which helped keep the air inside the batter. However, increasing the PPP amount had a negative

Table 2c. Sensory analysis of gluten-free cakes enriched with PPP and/or XG.

Sample		Sensory Analysis				
XG (%)	PPP (%, w/w)	Color	Texture	General Appearance	Flavor	Overall Liking
0	0	4.40 ± 0.75^{d}	3.83 ± 0.71^{abc}	4.30 ± 0.73^{d}	4.03 ± 0.73^{de}	4.03 ± 0.77^{bc}
	4	4.05 ± 0.51^{cd}	3.95 ± 0.69^{bc}	4.35 ± 0.59^{d}	4.35 ± 0.75^{de}	4.15 ± 0.75^{c}
	8	3.58 ± 0.67^{ab}	3.75 ± 0.64^{ab}	4.10 ± 0.72^{cd}	3.95 ± 0.76^{cde}	4.05 ± 0.51^{bc}
	12	3.48 ± 0.82^{ab}	3.55 ± 0.94^{ab}	3.58 ± 0.67^{ab}	3.20 ± 0.83^{a}	3.48 ± 0.64^{a}
0.5	0	4.20 ± 0.52^{cd}	3.90 ± 0.72^{bc}	4.25 ± 0.44^{d}	4.35 ± 0.58^{de}	4.05 ± 0.51^{bc}
	4	4.10 ± 0.55^{cd}	4.00 ± 0.73^{bc}	4.35 ± 0.59^{d}	4.35 ± 0.49^{de}	4.23 ± 0.62^{c}
	8	3.60 ± 0.68^{ab}	3.70 ± 0.57^{ab}	3.75 ± 0.64^{bc}	3.90 ± 0.72^{bcd}	3.70 ± 0.57^{ab}
	12	3.25 ± 0.44^{a}	3.35 ± 0.67^{a}	3.35 ± 0.59^{ab}	3.45 ± 0.76^{ab}	3.35 ± 0.67^{a}
1	0	4.40 ± 0.60^{d}	4.30 ± 0.47^{c}	4.35 ± 0.67^{d}	4.40 ± 0.60^{de}	4.30 ± 0.66^{c}
	4	4.05 ± 0.69^{cd}	3.90 ± 0.64^{c}	4.40 ± 0.50^{d}	4.45 ± 0.51^{e}	4.35 ± 0.59^{c}
	8	3.83 ± 0.82^{bc}	3.75 ± 0.64^{bc}	4.10 ± 0.64^{cd}	4.15 ± 0.67^{de}	4.05 ± 0.60^{bc}
	12	3.20 ± 0.52^{a}	3.70 ± 0.73^{ab}	3.25 ± 0.64^{a}	3.50 ± 0.95^{abc}	3.40 ± 0.68^{a}

Data are expressed as mean values of replicates ± standard deviation. Different letters within the same column indicate significant differences ($p < 0.05$) according to Duncan multiple comparison test.

Table 3. Numerical optimization of the amount of PPP and XG in formulation.

Number	XG	PPP	Specific Volume	Consistency Index	Overall Liking	Peak Viscosity	Breakdown Viscosity	Setback Viscosity	Desirability	
1	0.51	8	1.53106	151.965	3.83753	1.0481	0.368213	0.267637	0.522	Selected
2	0.51	8	1.53196	152.762	3.83761	1.04987	0.369091	0.267824	0.522	
3	0.37	4	1.53357	89.7122	4.13103	1.15662	0.44577	0.30607	0.478	

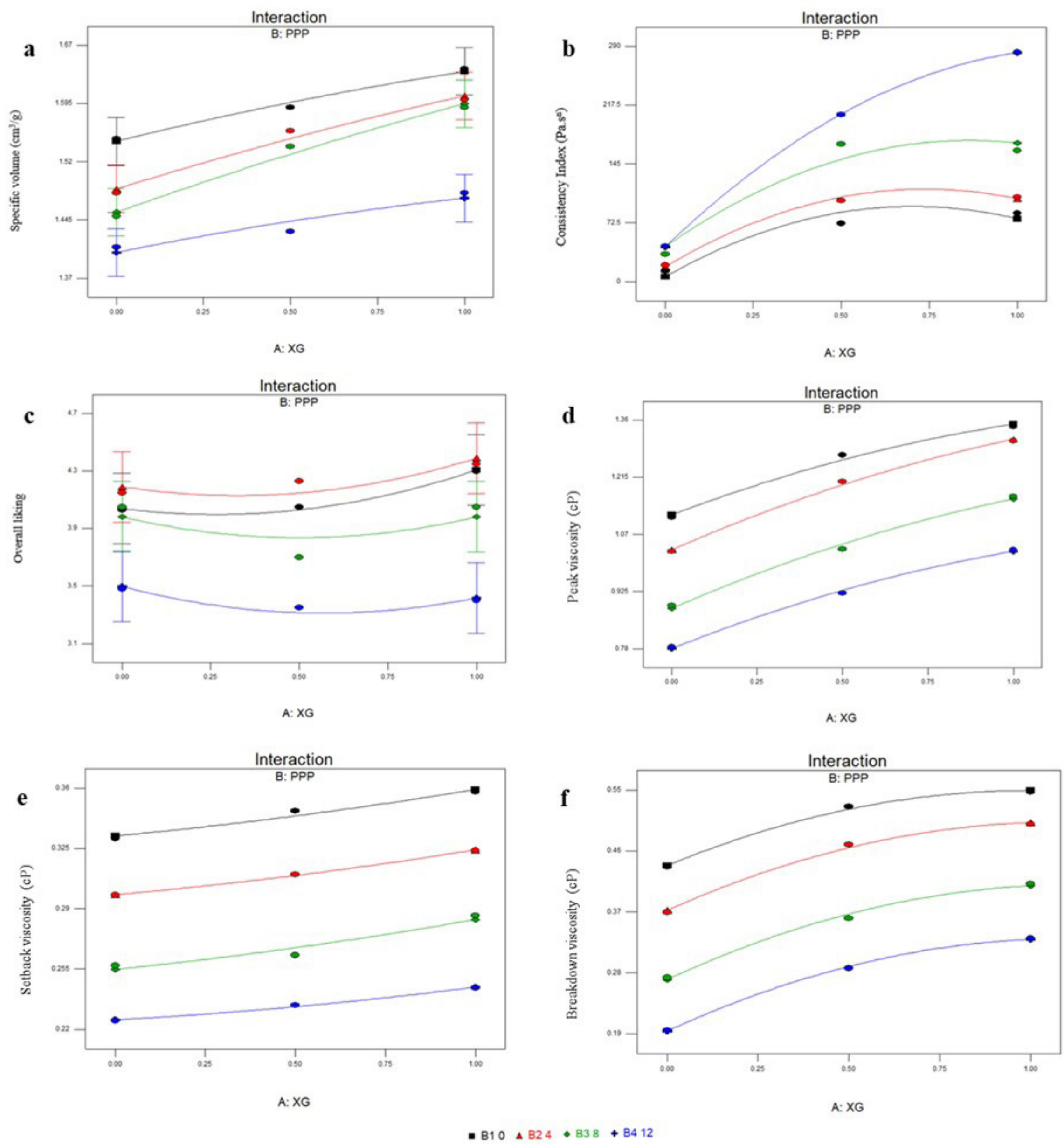

Figure 3. Interaction of PPP and XG on a) Specific volume of cakes, b) Consistency index of the batters, c) Overall liking, d) Peak Viscosity, e) Setback Viscosity, and f) Breakdown Viscosity.

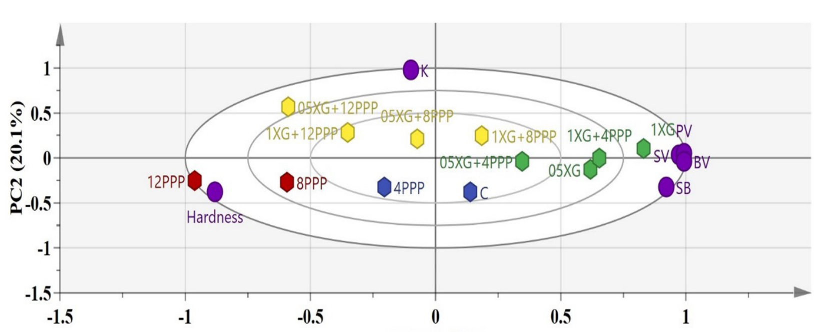

Figure 4. Biplot of principal component analysis of rheological properties of batters, pasting properties of flour blends, physical characteristics, and quality of gluten-free cakes (different colors indicate different groups of gluten-free batters) (PV: Peak viscosity, BV: Breakdown viscosity, SB: Setback viscosity, K: Consistency index (Power-law model), and SV: Specific volume).

impact on the ability of the material to form a viscous paste, thus causing the specific volume to decrease. The samples that have both XG and PPP together are separated from the other samples with the effect of PC2. However, the samples that have no PPP and 4% PPP clustered on the side closer to the specific volume, PV, and SB.

4 Conclusion

The enrichment of quinoa-based GFCs with PPP, XG, and their combination was evaluated. The study demonstrated that the PPP with high amounts of SDFs and IDFs could be deemed valuable sources of DFs for the enrichment of gluten-free products. The SDF and IDF from PPP and XG affected the rheological, physicochemical, and textural properties of GFCs. Usage of XG and PPP together can help to improve the rheological and textural properties of the final product due to their effects on WRC, pasting properties, and viscosity. PPP and XG showed opposite effects on pasting properties, specific volume, and hardness. Opposite effects that XG and PPP reveal on pasting properties aid in the formation of a more stable structure in the presence of both XG and PPP. Physicochemical properties, physical characteristics, and desirability analysis revealed that up to 8% of PPP and 0.5% XG addition were suitable for the enrichment of GFCs.

Conflict of interest

The authors declare that they have no conflicts of interest.

Availability of data and material

All data supporting the findings of this study are available and can be provided to anyone whenever appropriate.

Acknowledgments

This study was financially supported by Ege University, Scientific Research Project (BAP) Coordination Unit (Project No: 14 MUH 050).

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