Effects of whey and grape peels on pasta physical and sensory properties

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Keywords:

Grape by-product
Whey powder
Gluten-free
Pasta
Nixtamalized corn
Flour

Article history:

Received
14.04.2025
Received in revised form 12.05.2025
Accepted
30.06.2025

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DOI:
10.24263/2310-1008-2025-13-1-3

Abstract

Introduction. Grape peels and whey are nutritious by-product that can be used to develop innovative foods.

Materials and methods. Pasta was made from nixtamalized white corn flour, corn starch, whey powder (5, 10, 15%), and grape peel powder (1, 3, 5%). The analyses included water absorption, cooking loss, texture (breaking force of dry pasta and firmness of cooked pasta), color, surface roughness, and sensory profile.

Results and discussion. The results indicated that quadratic models effectively described the relationships between ingredients and pasta properties, with strong statistical fits (R^2 > 0.82). Both ingredients and their interaction influenced cooking solid loss, water absorption, texture, roughness, and color.

Addition of whey powder in the amounts of 5, 10, and 15% reduced cooking solid loss from 15.48 to 14.24% and surface roughness from 17.75 to 14.80 µm but also decreased pasta firmness from 286.84 to 238.95 g. In contrast, grape peel increased cooking solid loss from 15.52 to 17.58% and firmness from 244.16 to 325.83 g while also raising roughness up to 3% addition, after which roughness declined. Water absorption decreased from 230.74 to 217.56% with increased levels of both additives. Texture analysis showed breaking force increased from 3239.00 to 3910.91 g with grape peel but decreased with higher whey content up to 10%, then increased.

Color (Chroma) was significantly affected: whey increased Chroma from 18.89 to 20.83 for uncooked pasta and from 16.88 to 18.18 for cooked pasta, while grape peel reduced it from 19.81 to 13.34 for uncooked pasta and from 17.65 to 10.42 for cooked pasta. Strong correlations were observed between cooking solid loss, roughness, and color parameters.

Sensory analysis showed that the sample with the highest whey concentration of 15% and the lowest grape skin content of 1% had low cooking solids loss and roughness, and received the highest scores for appearance, texture, colour, smell, taste and overall acceptability.

Conclusion. The results highlight the potential of specific combinations of whey and grape skin to enhance the quality of gluten-free pasta, providing valuable insights for product development.

Introduction

Growing global demand for healthier food options and the urgent need to address environmental concerns related to food industrial waste have spurred extensive research into fortification of staple foods, including baked goods (Stabnikova et al., 2023a, b). An example of such products is pasta, which is a widely consumed and affordable product with a long shelf life, serves as an ideal matrix for incorporating various by-products and protein concentrates to enhance its nutritional and functional attributes (Sissons, 2022; Stamatovska and Nakov, 2022; Ungureanu-Iuga et al., 2020). This approach not only provides valuable applications for industrial by-products, which are often produced in large quantities and pose disposal challenges, but also enriches the nutritional profile of common foods, offering consumers products with added health benefits (Simonato et al., 2019). The use of grape pomace, a winemaking by-product rich in various biologically active compounds, in bakery and confectionery technologies has attracted increasing attention (Grevtseva et al., 2023; Mironeasa et al., 2024; Stabnikova et al., 2021; Tolve et al., 2020).

Grape pomace peel is a valuable residue from winemaking, rich in antioxidant polyphenols, including various phenolic acids and flavonoids, and provides significant amounts of dietary fiber, helping to address common deficiencies in Western diets (Gaita et al., 2020). Increased dietary fiber intake can enhance satiety, reduce energy intake by lowering the bioavailability of fatty acids, improve glycemic control, and reduce the risk of type II diabetes and cardiovascular disease (Jane et al., 2019).

Meanwhile, whey protein and its derivatives are highly valued for their exceptional nutritional content and functional versatility, offering benefits such as immune support and improved cardiovascular health (Wani et al., 2015). Whey protein concentrate is often selected for fortifying various food products due to its favorable nutritional composition, cost-effectiveness, and wide availability (Kochubei-Lytvynenko et al., 2022; Komeroski and Oliveira, 2023; Prabhasankar et al., 2007). The incorporation of these ingredients significantly impacts several key quality parameters of pasta and other food products.

Fortification with fiber-rich by-products like grape peel often increases cooking loss, primarily due to the disruption of the gluten network (Ajila et al., 2010; Simonato et al., 2019). This effect can lead to more solids leaching into the cooking water. It has been proven that the combination of sodium caseinate and whey protein concentrate effectively reduces cooking loss in depigmented pearl millet-based gluten-free pasta (Kumar et al., 2019). The effect on pasta firmness varies depending on the specific by-product and its concentration. For example, olive pomace and mango peel fortification can increase pasta firmness due to the resistance provided by dietary fiber particles or the formation of a denser structure within the pasta matrix (Ajila et al., 2010; Simonato et al., 2019). By-product incorporation frequently alters the pasta's color, which is a significant factor in consumer perception. Overall consumer acceptability is crucial for the market success of fortified products. The high content of fiber-rich ingredients, such as fruit pomace, in the pasta led to reduced consumer acceptability (Ajila et al., 2010; Gaita et al., 2020). Notably, instant noodles fortified with ultrasound-modified whey protein achieved significantly higher sensory scores across multiple attributes, including surface appeal, hardness, stickiness, bite quality, mouthfeel, and overall acceptability.

While challenges in maintaining acceptable technological and sensory attributes exist, advancements in ingredient selection and processing techniques are proving effective in mitigating these issues, paving the way for market-ready functional foods. In this context, this paper aimed to investigate the combined effects of whey powder and grape peel on gluten free pasta based on nixtamalized corn flour. For this purpose, the cooking behavior, texture, color, roughness and sensory characteristics were considered.

Materials and methods

Materials

The ingredients used for the pasta included nixtamalized white corn flour, unhydrolyzed sweet commercial whey powder, corn starch, and grape peel powder, all purchased from a local market in Romania. The recipe for pasta samples comprised a starch-corn flour mix, whey powder, and grape peel powder, combined in varying proportions. This mixture also included 0.50% salt and 50% water (at 25 °C) to achieve optimal dough development.

Pasta dough was mixed for five minutes in a heavy-duty mixer and then extruded into rigatoni using a short pasta accessory. The pasta drying process included: air-drying for 30 min at room temperature, oven-drying with continuous ventilation for 60 min at 40 °C, followed by 120 min at 80 °C, and another 120 min at 40 °C. Finally, the pasta was cooled for 12 h at room temperature (Bergman et al., 1994).

Cooking characteristics

The water absorption capacity was determined in triplicate, adhering to the methodology delineated by Giménez et al. (2015). A 10 g sample of pasta was immersed in 200 mL of distilled water and subjected to boiling until the previously established optimal cooking time was achieved. Subsequently, the samples were drained for 3 min and their mass recorded.

The cooking loss of solids (CSL) was evaluated by collecting the cooking water obtained from the water absorption determination. This water was then placed into glass containers and dried in an oven at 105 °C to constant (Giménez-Bastida et al., 2015). The mass of the residual solids was subsequently measured, with the procedure replicated three times.

Texture determination

A Perten Instruments TVT-6700 texture analyzer, fitted with a 10 kg load cell, was used to determine the textural parameters of pasta samples.

The breaking force of dry pasta was evaluated through a three-point bend test utilizing an aluminum break probe with a 13 mm width. Each pasta piece was cut at a test speed of 3 mm/s, initiated by a 50 g trigger force. The maximum force needed to fracture the pasta was reported as its breaking force. Five measurements were conducted for each sample.

For cooked pasta firmness, a single-cycle compression method was applied. An AACC 16-50 transparent noodle probe was used, set at 0.5 mm above the scale plate, with a test speed of 0.2 mm/s. Two cooked pasta pieces were positioned on a heavy-duty stand (BB) with a polythene protection insert (HDS) and analyzed as detailed above. These measurements were performed in triplicate (Ungureanu-Iuga et al., 2020).

Color evaluation

To characterize the color of dry and cooked pasta, a Konica Minolta CR-400 colorimeter (Tokyo, Japan) was employed. The L*, a*, and b* color parameters (lightness, red-green intensity, and yellow-blue intensity, respectively) were recorded from the CIE-Lab system via reflectance measurements. Five measurements were performed for every sample to ensure consistent data collection. Chroma was calculated using equation:

$$Chroma = \sqrt{a^{*2} + b^{*2}}$$

Roughness analysis

To evaluate pasta roughness, a Mahr CWM100 microscope (Gottingen, Germany) was employed. Four distinct areas of each sample were observed, and the resulting data was subsequently analyzed using the trial version of Mountain Map software (Digital Surf, France) version 8. Roughness values were recorded in triplicate, representing the mean of computed profiles from three of the examined areas.

Sensory profile

Sensory evaluation of the pasta samples was conducted in two separate sessions by a panel of 9 semi-trained judges. The judges assessed various attributes, including color, taste, smell, texture, appearance, and overall acceptability. For evaluation, pasta samples were boiled to their predetermined optimal cooking time, then presented on white plates with a single drop of olive oil on each piece. A nine-point hedonic scale was utilized to quantify the preference for each sensory characteristic.

Statistical data processing

Data processing was done by using Design Expert (trial version). Samples were prepared as described in our previous work (Ungureanu-Iuga et al., 2020). The influence of whey (factor A) and grape peel (factor B) was evaluated by using quadratic model. To confirm the models' suitability, Analysis of Variance (ANOVA) was conducted ($p < 0.05$), taking into account the F-value, p-value, R^2, *Adjusted* R^2, and *Predicted* R^2. Whey concentration was 5, 10 or 15%, while grape peel concentration was 1, 3 of 5%. The difference between the selected samples were evaluated trough ANOVA with Tukey test ($p < 0.05$) using XL STAT 2024 version.

Results and discussion

Effects of whey and grape peels on pasta physical characteristics

Gluten free pasta quality represents a challenge for researchers and producers. The impact of whey powder and grape peel on corn pasta characteristics is described by the quadratic models (Table 1) which fitted well the experimental data ($R^2 > 0.82$, $p < 0.01$).

CSL and pasta water absorption were significantly affected by both factors (whey and grape peel), as well as their interaction (Table 1). While whey powder determined a decrease of the amount of solids released during cooking, grape peel exhibited a reversed trend. Sufficient protein can strengthen the protein network of gluten free pasta, reducing cooking loss. Adding whey powder led to starch retention within the protein matrix, improving cooked pasta shape and dough extensibility (Zhao et al., 2024). Similar to the results obtained by Zhao et al. (2024), whey powder specifically decreased gluten-free pasta's cooking loss by forming a surface film that created a tight network which inhibited starch granule expansion during gelatinization, thus minimizing cooking loss. The inclusion of by-products, particularly those rich in fiber like grape peels, disrupts the gluten and starch matrix by enhancing water penetration and competing with starch for moisture, thereby weakening the formation of a strong structural network in the pasta and leading to higher cooking loss (Dey et al., 2021).

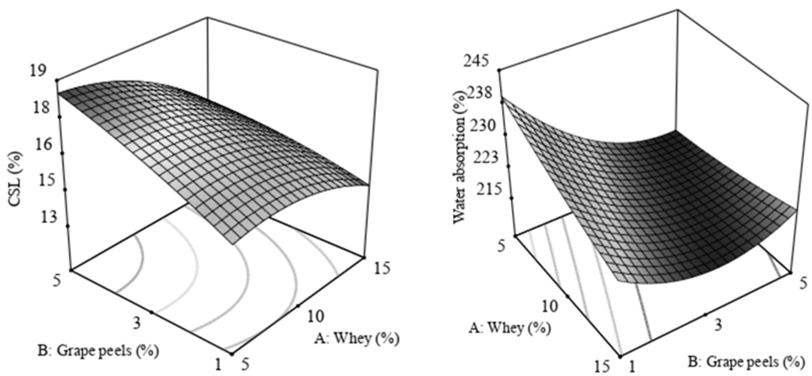
Table 1

ANOVA results for the evaluation of whey (A) and grape peels (B) impact on pasta quality

Factor	CSL (%)	Water absorption (%)	Breaking force (g)	Firmness (g)	Chroma uncooked	Chroma cooked	Roughness (µm)
Const.	16.78	217.57	3774.78	311.96	15.17	12.52	21.56
A	-1.09**	-2.55**	236.39**	18.06*	0.72**	-0.17	-1.98**
B	1.03**	-6.59**	335.61**	40.83**	-3.23**	-3.61**	1.67**
AB	-0.48**	5.19**	-288.42**	42.00**	-0.26	-0.81*	-0.51
A^2	-0.66**	0.78	682.83**	18.72	0.05	-0.12	1.41*
B^2	-0.22	6.58**	-199.17	-26.94*	1.40**	1.52**	-5.01**
Model evaluation							
p	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
R^2	0.91	0.93	0.82	0.82	0.97	0.89	0.90
Adj. R^2	0.89	0.91	0.78	0.78	0.96	0.86	0.88
Pred. R^2	0.84	0.88	0.71	0.71	0.95	0.81	0.83

** – significant at $p < 0.01$, * significant at $p < 0.05$.

Water absorption decreased significantly ($p < 0.05$) as the addition level of both whey and grape peel increased (Figure 1). The negative effect of whey can be due to milk proteins which competitively reduce the water necessary for starch swelling during gelatinization (Kumar et al., 2019). Similar reduction of water absorption was observed for pearl millet gluten-free pasta when sodium caseinate and whey concentrate were added (Kumar et al., 2019). Padalino et al. (2018) also reported the increase of water absorption when olive pomace was incorporated in pasta. The increased water absorption observed with higher grape peel content in pasta can be attributed to several factors: higher pectin content (especially hydrophobic, highly methylated pectin's), the ability of polyphenols to form hydrogen bonds with other macromolecules, and the presence of mineral components (Gumul et al., 2023).



a b

Figure 1. Combined effects of whey (A) and grape peels (B) on pasta cooking behavior: a) cooking loss of solids (CSL) and b) water absorption

Texture parameters, namely dry pasta breaking force and cooked pasta firmness were significantly influenced by both additions of whey and grape peel and their interaction (Table 1). Breaking force decreased when whey was included in corn pasta formulation up to 10%, then increased. An increase in breaking force was observed when pea protein flour was incorporated into gluten-free amaranth pasta, a finding also reported by (Gupta, 2019). Drawing from Belton's gluten model, which differentiates between linear glutenin proteins (contributing elasticity through disulfide and hydrogen bonds) and globular gliadin proteins (providing viscosity and slowing elastic recovery), it is proposed that whey proteins may either mimic gliadins by increasing viscosity and decreasing elasticity, or directly interfere with glutenin's structure by forming hydrogen and disulfide bonds, ultimately leading to a disruption of the gluten network (Prabhasankar et al., 2007).

Grape peel incorporation led to higher breaking force (Figure 2). Antioxidant compounds are hypothesized to strengthen the gluten network during both pasta dough production and the subsequent drying process (Gałkowska et al., 2022).

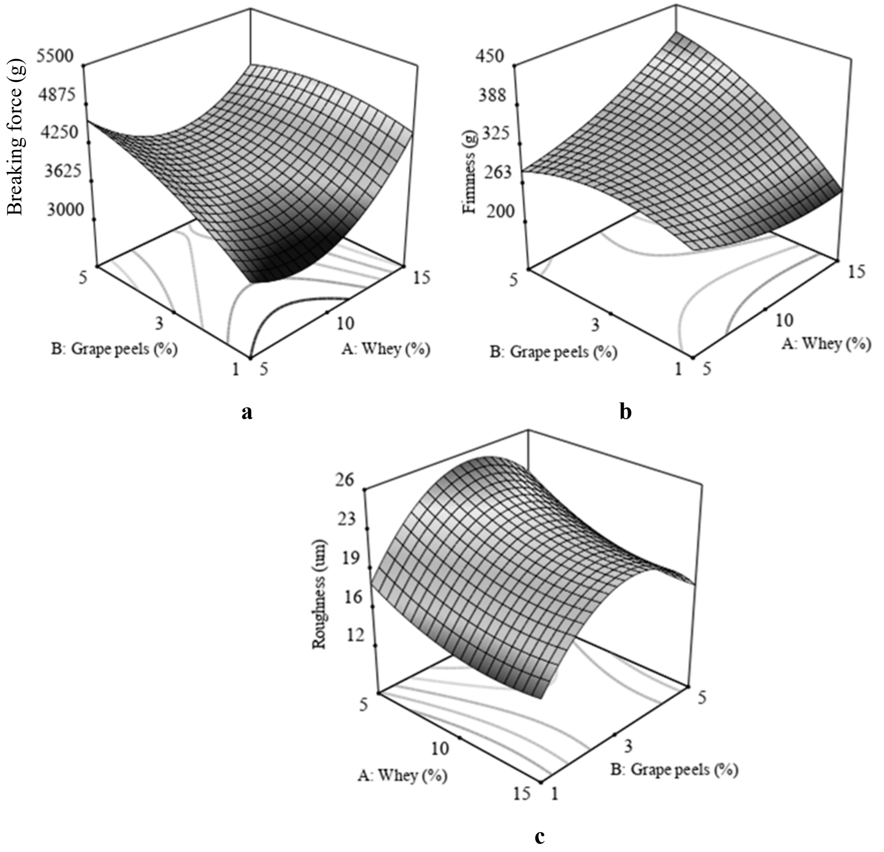
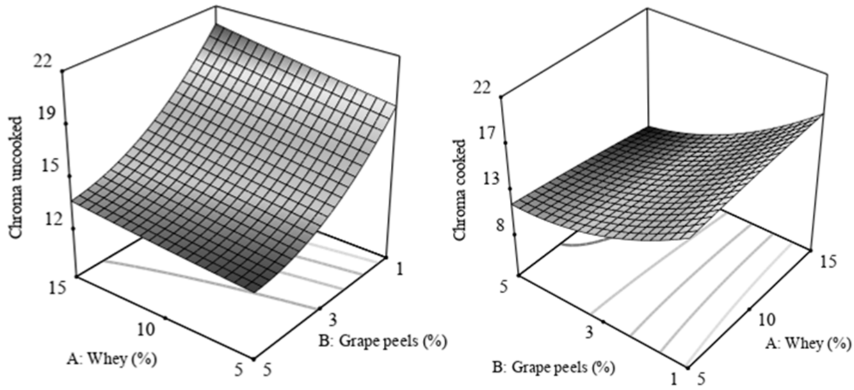


Figure 2. Combined effects of whey (A) and grape peels (B) on pasta texture: a – dry pasta breaking force, b – cooked pasta firmness, and c – roughness

Whey powder determined a decrease in cooked pasta firmness, while the opposite trend was observed for grape peel addition (Figure 2). It's possible that whey proteins contribute to reduced firmness by forming distinct entities rather than a cohesive protein gel (Kumar et al., 2019). Furthermore, sulfhydryl groups in whey proteins may oxidize gluten's disulfide bonds, which is hypothesized to reduce firmness (Kumar et al., 2019). Other studies reported that the addition of mango peel powder and olive pomace was found to increase pasta firmness, suggesting that fiber-rich by-products may enhance texture by contributing structural resistance through their dietary fiber content (Ajila et al., 2010; Simonato et al., 2019).

Roughness was affected significantly ($p < 0.05$) by both factors, but their interaction had a non-significant effect. Incorporation of whey powder in corn pasta was proved to exert a beneficial effect of pasta roughness by decreasing this parameter (Figure 2). Grape peel addition up to 3% led to an increase in surface roughness, then it decreased. Komeroski and Oliveira (2023) reported that whey can enhance water binding and stabilize dough, which in turn contributes to smoother texture and surface refinement in pasta products—suggesting a reduction in surface roughness. Aravind et al. (2012) reported that adding dietary fiber resulted in more irregular and uneven wheat spaghetti surfaces, potentially leading to a fragile structure.

Uncooked pasta color described by Chroma was significantly affected ($p < 0.05$) by whey and grape peel addition, but not by their interaction (Table 1). Cooked pasta Chroma was influenced significantly ($p < 0.05$) only by grape peel quantity and its interaction with whey powder. The combined effects of whey and grape peels addition on pasta color are displayed in Figure 3.



a b

Figure 3. Combined effects of whey (A) and grape peels (B) on pasta color: a – dry pasta Chroma; b – cooked pasta Chroma

Whey powder incorporation led to higher Chroma values as the level increased for both uncooked and cooked pasta. On the other hand, grape peel level increase led to a progressive reduction in both uncooked and cooked pasta Chroma (Figure 3). It has been stated that cookies exhibited changed color when whey protein was added, likely due to sugar caramelization and whey protein darkening during baking, with general compounds degradation also contributing to color changes (Wani et al., 2015). Tolve et al. (2020)

reported changes in pasta color as the addition level on grape pomace was higher due to the presence of pigments in the ingredient added.

Correlations between variables

The relationships between dependent variables and factors are shown in Figure 4.

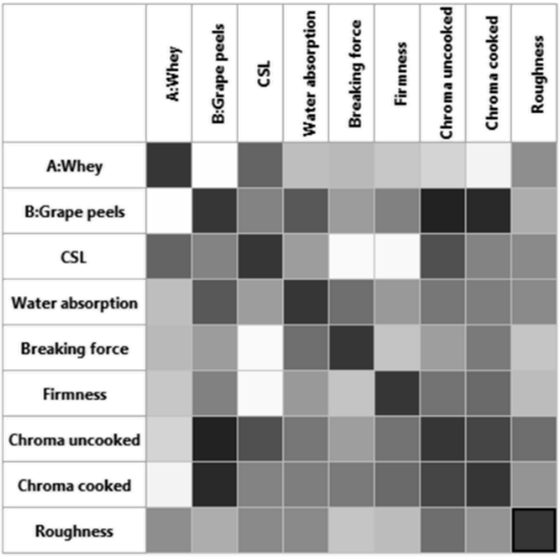
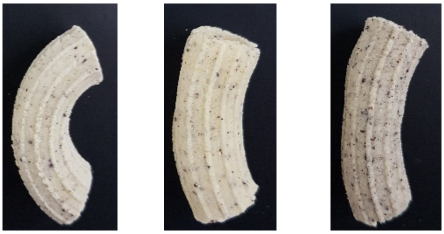


Figure 4. Correlations between variables

CSL was negatively correlated with both uncooked and cooked Chroma ($p < 0.05$, r = -0.74, r = -0.52 respectively), and positively with pasta roughness ($p < 0.05$, r = 0.58). Water absorption was negativley correlated with dry pasta breaking force ($p < 0.05$, r = -0.61), and positively with both color parameters ($p < 0.05$, r > 0.63). This is consistent with previous statements that incorporation of fiber-rich ingredients led to changes in pasta network, a weak structure absorbing more water and causing higher release of solids during cooking (Dey et al., 2021). Strong positive correlation ($p < 0.05$, r = 0.92) was obtained between uncooked and cooked pasta Chroma. Negative correlation was obtaine between roughness and uncooked pasta Chroma ($p < 0.05$, r = -0.61).

For further sensory characterization, the samples with the highest water absorption, breaking force, Chroma, and the lowest cooking loss of solids and roughness were selected (pasta firmness was considered in range). Thus, sample P1 contains 5% whey and 1% grape peels, P3 contains 15% whey and 1% grape peels, and P6 contains 15% whey and 3% grape peels (Figure 5) were evaluated.



P1 P3 P6

Figure 5. Appearance of selected pasta

Physical and sensory characteristics of the selected samples

The characteristics of the selected samples are displayed in Table 2.

Table 2

Physical characteristics of the selected samples

Variable	Sample		
	P1	P3	P6
Whey (%)	5	15	15
Grape peels (%)	1	1	3
CSL (%)	15.69 ± 0.48^{a}	14.24 ± 0.48^{b}	15.09 ± 0.48^{ab}
Water absorption (%)	236.54 ± 2.31^{a}	223.78 ± 2.31 ^{b}	215.73 ± 2.31^{c}
Breaking force (g)	3510.22 ± 269.03^{b}	4447.64 ± 269.03^{a}	4696.74 ± 269.03^{a}
Firmness (g)	292.43 ± 25.93^{b}	238.96 ± 25.93^{b}	359.46 ± 25.93^{a}
Chroma uncooked	18.26 ± 0.57^{b}	20.84 ± 0.57^{a}	15.49 ± 0.57^{c}
Chroma cooked	16.25 ± 1.26^{a}	18.18 ± 1.26^{a}	11.66 ± 1.26^{b}
Roughness (μm)	19.06 ± 1.23^{a}	14.80 ± 1.23^{b}	21.05 ± 1.23^{a}

$^{a\text{-}c}$ – different letters in the same row indicate significant differences between samples ($p < 0.05$).

The smaller CSL was observed for the sample with the highest whey concentration (15%) and the lowest grape peel level (1%), namely P3. Whey powder could interact with starch to form a stronger matrix which led to lower CSL, similar observations being made by (Khatkar et al., 2024). Reports indicate that incorporating fiber-rich ingredients like grape peel can elevate cooking loss due to its potential to disrupt and weaken the starch-gluten network. This disruption may accelerate starch gelatinization, thereby facilitating increased leaching of gelatinized starch from the pasta during cooking (Tolve et al., 2020). The highest water absorption was observed for P1 which contained the lowest whey and grape peels amounts. Water absorption in pasta is linked to starch swelling and gelatinization, but it can be restricted by protein polymerization forming a network that entraps starch granules during drying and cooking, while gluten dilution and fiber-starch competition for water also play a role (Gałkowska et al., 2022). The sample with 15% whey and 3% grape peel (P6) exhibited the greatest breaking force and firmness, and the lowest Chroma for both uncooked and cooked state. The results were in agreement with previous study regarding the effects of blackcurrant pomace on durum wheat pasta (Gałkowska et al., 2022).

It's possible that an optimal spatial distribution of grape peel fiber particles within the pasta structure contributed to its increased firmness (Gałkowska et al., 2022). The smallest roughness was obtained for 15% whey and 1% grape peel (P3). This can be due to the presence of fibers in dough matrix which disrupted gluten matrix. On the other hand, whey could promote the formation of stronger smoother networks (Khatkar et al., 2024).

Sensory analysis of the selected samples revealed that the sample with the highest whey concentration (15%) and the lowest grape peel amount (1%) – P3, obtained the best scores for appearance, texture, color, smell, taste and general acceptability, followed by P6 with 15% whey and 3% grape peel and P1 with 5% whey and 1% grape peel (Figure 6).

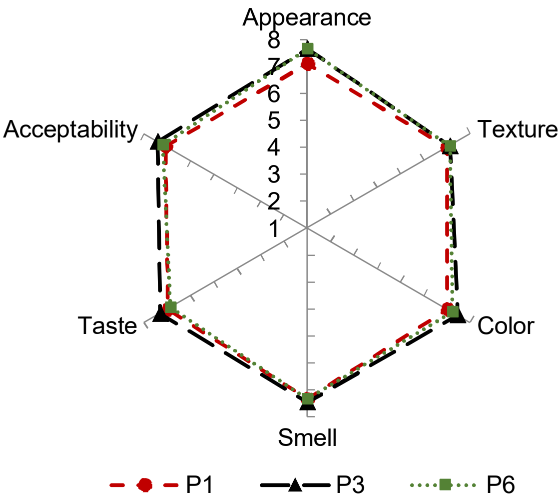


Figure 6. Sensory properties of the selected samples

It has been stated that incorporating whey into bakery and pasta products offers technological, nutritional, and sensory benefits, including enhanced sensory attributes (Komeroski and Oliveira, 2023). On the other hand, high amounts of fiber-rich ingredients like grape peel led to lower sensory characteristics, similar to the results reported by Gaita et al. (2020).

Conclusions

This research successfully demonstrated the significant impact of whey powder and grape peel powder on the quality of gluten-free corn pasta. Quadratic models accurately described these effects, showing strong fits to experimental data. Whey powder consistently improved pasta quality by decreasing cooking loss (CSL), reducing water absorption, and lowering roughness. It also increased both uncooked and cooked pasta Chroma as color intensity. Conversely, grape peel generally led to increased CSL and roughness, while reducing Chroma. However, grape peel positively influenced breaking force and cooked pasta firmness. The interplay of these ingredients is crucial. For instance, increasing whey initially decreased breaking force, while grape peel increased it. Notably, the sample with 15% whey, 1% grape peel emerged as superior, exhibiting the lowest CSL and roughness, and achieving the best sensory scores across all attributes. This highlights the potential of specific whey and grape peel combinations to enhance gluten-free pasta quality, offering valuable insights for product development.

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Cite:

UFJ Style

Ungureanu-Iuga M., Cobuz C. (2025), Effects of whey and grape peels on pasta physical and sensory properties, *Ukrainian Journal of Food Science*, 13(1), pp. 5–16, https://doi.org/10.24263/2310-1008-2025-13-1-3

APA Style

Ungureanu-Iuga, M., & Cobuz, C. (2025). Effects of whey and grape peels on pasta physical and sensory properties. *Ukrainian Journal of Food Science, 13*(1), 5–16. https://doi.org/10.24263/2310-1008-2025-13-1-3