Advance on the Capitalization of Grape Peels By-Product in Common Wheat Pasta

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Abstract: Capitalization of winery by-products has received high interest among scientists, producers and consumers concerned with healthy diet and environment protection. Grape peels are rich in fiber and polyphenols and can be used as ingredients in pasta matrix in order to increase the nutritional and functional value of such a staple food. The aim of this paper was to investigate the effects of grape peel flour added in various amounts (1–6%) to common wheat pasta dough viscoelasticity and texture and on pasta chemical composition, color, cooking behavior and texture, revealing at the same time the relations between characteristics. Grape peel flour induced the increase of the elastic (G’) and viscous (G”) moduli, dough hardness, springiness, cohesiveness, pasta crude ash, crude fat, crude fiber, total polyphenols and resistant starch contents, pasta water absorption, cooking loss and breaking force as the addition level was higher and compared to the control. On the other hand, dough resilience, pasta luminosity, chewiness and firmness decreased as the amount of grape peel flour raised. Significant correlations (p < 0.05) were obtained between the chemical composition and color parameters, while crude fiber, protein and fat were correlated with dough and pasta texture, total polyphenols with resistant starch content, cooking loss with crude fiber and dough textural parameters. The obtained results underlined the opportunity to use a valuable byproduct such as grape peels in novel pasta formulations, being helpful for processors to extend the product variety and to optimize the processes in order to better satisfy consumer’s demand for functional foods.

Keywords: common wheat; vinification by-product; texture; dough rheology; physico-chemical properties

1. Introduction

Food processing trends are heading more and more to waste reduction and sustainable approaches in order to diminish the impact of these activities on the environment. Large amounts of by-products resulted can be used as alternative ingredients to create value-added food or extract bioactive compounds. One of the industries that generate byproducts with high functional properties is winemaking. Grape vine (Vitis vinifera L.) is cultivated all over the world, the total surface in 2020 summing up more than 7.3 million hectares, with a production of 230 mhl wine [1]. Grape pomace represents about 20–30% of the grape weight, with grape peel counting 63–75% of the total pomace [2]. Therefore, the disposal of such by-products greatly impacts the environment, the main uses being oriented towards animal feed or compost. Furthermore, some processors resort to the discarding of grape pomace on the soil without any pretreatment which will determine acidification due to the low pH of pomace and oxygen consumption in soil and ground waters caused by tannins and other compounds’ presence [3,4].

Common wheat flour is used for pasta production mainly in countries where durum wheat is less accessible and more expensive [5]. Refined wheat flour presents a low nutritional value due to its proximate composition, grain parts like bran and endosperm...
are discarded during milling, depending on the extraction rate. Refined wheat flour has an extraction rate of 75% and thus presents low amounts of fiber, vitamins, minerals and bioactive compounds compared to whole wheat [6,7]. The lack of fiber in the human diet could be related to negative effects on the digestive system. Thus, the supplementation of wheat flour with various fiber-rich ingredients drew increasingly attention from researchers and producers.

Grape by-products give many health benefits due to the presence of bioactive compounds which are kept in grape pomace even after processing. Grape pomace has more than 60% dietary fiber [7,8], the main fraction being insoluble dietary fiber represented by cellulose and hemicelluloses. Nevertheless, soluble dietary fiber is also found in grape by-products and exerts many health benefits given by water-soluble polysaccharides such as β-glucan, pectin and gum [9]. It was demonstrated that grape pomace could act as a prebiotic in the colon due to its ability to ferment, acting as a substrate for the colon microbiota [7,10]. Grape by-products bioactive compounds include flavonoids such as anthocyanins, resveratrol, tannin and quercetin with antibacterial, anticancer, antioxidant and anti-inflammatory activities, hepatic and cardiovascular protection and chronic diseases prevention properties [11–15]. The proximate composition of grape pomace includes proteins, lipids and carbohydrates, the main micronutrients represented by vitamins and phenolic compounds that exert antioxidant activity against free-radicals [16,17]. The chemical composition of grape by-products depends on various factors such as cultivar, climate, ripening stage and soil [18].

In food products supplementation for functional value increase, the use of valuable bioactive compounds is an essential goal to satisfy the diversified, escalating market demand. There are some studies revealing the possibility to use wine grape by-products such as pomace, peels and seeds in bakery and pasta products, as it was summarized in our previous work [19]. According to the results presented by Marinelli et al. [20], grape marc incorporation in durum wheat pasta led to significant improvement of phenolics and anthocyanins contents and antioxidant activity compared to the control, higher bioaccessibility of polyphenols and lower glycemic index being obtained. Regarding cooked pasta texture, a decrease of firmness, adhesiveness and elasticity was reported, probably due to the gluten dilution effects [20]. Lou et al. [21] observed an increase in antioxidant activity and radical scavenging activities of biscuits enriched with grape pomace, while minor influence on the digestion rate was recorded. Furthermore, biscuits chewiness and hardness increased as the level of grape pomace was higher possibly as a result of the binding of polyphenols with protein or starch, determining a raised gluten matrix strength [21]. Textural properties of breadsticks were affected by grape pomace incorporation, revealing a decrease in hardness and breaking force proportional to the level added, while the antioxidant capacity and the fiber content increased, as stated by Rainero et al. [22]. The addition of grape peels, seeds and pomace flours in wheat dough caused the decrease of the elastic (G') and viscous (G'') moduli, increasing at the same time tan δ values as the amount added raised [23]. The viscoelastic character of dough is related to its three-dimensional matrix given by the interaction between gluten proteins and starch or non-starch polysaccharides [24]. Balli et al. [25] studied the effect of 7% grape pomace addition in durum tagliatelle pasta and showed that pasta samples contained the same monoglycosylated and acetylated anthocyanins as found in grape pomace, while a good cooking resistance and texture after cooking were maintained. The incorporation of growing quantities of grape pomace flour in cakes led to the gradual increase of ash, lipid, proteins, fibers, free phenolics, anthocyanins, total polyphenol content and antioxidant activity, while the luminosity (L*) and the red nuance (a*) were reduced [4]. The most abundant phenolics identified in the enriched cakes were catechin, gallic acid, quercitin, protocatechuic acid, kaempferol and apigenin [4].

Our previous research [26,27] underlined the effects of grape peels on gluten free pasta made of corn flour and optimized the processing parameters for grape peels addition and hydrothermal treatment of wheat flour. Considering the factors mentioned above and the scarcity of papers regarding the influence of grape peel flour incorporation in
common wheat pasta, this study aimed to clarify the contribution of this by-product on the rheological and textural behavior of dough, on pasta chemical properties, color parameters, uncooked pasta breaking force, cooking behavior and cooked pasta texture. The positive effects of grape peel flour on final product functionality were evidenced by fiber, total polyphenols and resistant starch determination. Compared to our previous research, this study aimed to evaluate dough rheology in terms of elastic and viscous moduli, dough texture regarding hardness, resilience, springiness and cohesiveness, pasta proximate composition, pasta color in terms of luminosity, red-green and blue-yellow nuances and pasta texture parameters such as elasticity, firmness and chewiness, and in order to complete the image of grape peel’s influence on common wheat pasta. Furthermore, the correlations and the similarities between characteristics and samples were pointed out to better understand the interactions between wheat and grape peel flours components.

2. Materials and Methods

2.1. Materials Conditioning and Pasta Making

Common wheat (*Triticum aestivum*) flour (650 type) and grape peels from the Fetească Regală pomace were used in pasta making. This variety of grape peel was chosen in order to minimize the negative effects on color changes of the final product and taking into account that browner color is associated by the consumers with health, as stated in the literature [28].

Grape peel flour presented lower luminosity ($L^* = 62.42 \pm 0.07$) compared to wheat flour ($L^* = 89.49 \pm 0.42$), a red nuance ($a^* = 3.24 \pm 0.05$) compared to the green nuance of wheat flour ($a^* = -5.04 \pm 0.04$) and a higher yellow nuance (grape peel flour $b^* = 25.32 \pm 0.04$, wheat flour $b^* = 15.36 \pm 0.12$). Wheat flour proximate composition included $0.96 \pm 0.02\%$ crude fat, $12.39 \pm 0.18\%$ crude protein, $72.11 \pm 0.08\%$ carbohydrates, $0.52 \pm 0.04\%$ crude ash, $14.01 \pm 0.16\%$ moisture, $10.56 \pm 0.44$ mg GAE/100 g total polyphenols.

For grape peel flour processing, the fresh pomace was dehydrated in a convection oven at $50 \degree C$ for $18$ h, then stems and seeds were manually removed. The resulted product, called grape peel, was ground and sieved to a particle size $< 180 \mu m$. Grape peel flour proximate composition comprised $2.30 \pm 0.17\%$ crude fat, $9.06 \pm 0.06\%$ crude proteins, $25.25 \pm 0.05\%$ crude fiber, $51.27 \pm 0.20\%$ carbohydrates, $4.11 \pm 0.03\%$ crude ash, $8.00 \pm 0.08\%$ moisture and $133.27 \pm 1.44$ mg GAE/100 g total polyphenols.

For composite flours making, wheat flour was mixed for $15$ min in a Yucebas Y21 machine (Izmir, Turkey) with the appropriate amount of grape peel flour ($1\%$, $2\%$, $3\%$, $4\%$, $5\%$ or $6\%$ replacing wheat flour).

Pasta dough was made by mixing the composite flour in a Kitchen Aid mixer (Whirlpool Corporation, Tulsa, OK, USA) with appropriate amounts of water calculated to achieve $40\%$ moisture. After $15$ min of resting at room temperature in closed glass containers, pasta dough was extruded by using a rigatoni mold of the Kitchen Aid machine. Modeled pasta was dried in agreement with the protocol described by Bergman et al. [29]: pasta were dried for $30$ min in open air at room temperature, then the samples were placed in a convection oven for $60$ min at $40 \degree C$, then for $120$ min at $80 \degree C$ and finally for $120$ min at $40 \degree C$ (Figure 1).

2.2. Dough Visco-Elasticity Evaluation

For the rheological measurements, dough samples were previously laminated and left in closed containers for $30$ min to allow internal strain elimination. The viscous ($G'$) and elastic ($G''$) moduli were evaluated trough a frequency sweep test by means of a ThermoHAAKE, MARS 40 (Karlsruhe, Germany) dynamic rheometer with parallel plates (40 mm diameter). $G'$ and $G''$ variation with frequency in the range of $0.1–20$ Hz was evaluated at a strain of $15$ Pa which was in the linear viscoelastic region (LVR) previously tested.
Pasta exterior diameter before drying varied between 1.15 and 1.20 cm and the length was comprised between 2.73 and 2.94 cm, while after drying the diameter varied from 1.00 to 1.10 cm and the length from 2.50 to 2.70 cm. Control and enriched pasta samples with 1 to 6% grape peel flour (GP) are presented in Figure 2.

![Pasta making process](image)

**Figure 1.** Pasta making process.

2.3. Texture of Dough Evaluation

Texture profile analysis of dough was made by double compression on balls of 50 g weight, at 50% height, with 5.0 mm/s test speed and a trigger force of 20 g, by using a Perten TVT-6700 texturometer (Perten Instruments, Hägersten, Sweden) [26]. Dough hardness, resilience, springiness and cohesiveness were recorded.

2.4. Chemical Compounds Determination

The chemical compounds in terms of moisture, crude ash, crude protein and crude fat from pasta samples were evaluated according to the Romanian and International standard methods: (SR EN ISO 712/2010), (SR ISO 2171/2002), (SR EN ISO 20483/2007) and (SR 91/2007), respectively [5]. The dietary fiber contents were estimated with a FOSS 6500 NIR (FOSS NIRSystems, Silver Springs, MD, USA) infrared spectrometer, the calibration being made using the off the shelf INGOT commercial calibrations (AUNIR, Towcester, UK). The carbohydrates were calculated by difference (Equation (1)).

\[
\text{Carbohydrates} \% = 100 - (\text{moisture} + \text{ash} + \text{protein} + \text{lipid} + \text{fiber}) \tag{1}
\]

The total polyphenols were determined by following Folin–Ciocalteu protocol [30]. For this purpose, grinded pasta samples were extracted with methanol 80% (v/v) and sonicated at 37 °C and 45 Hz for 40 min [31]. After filtering, Folin–Ciocalteu reagent (1N) and sodium carbonate 20% (v/v) were added in the diluted extract (1:4). After 40 min of resting away from light, the absorbance was read at 725 nm and the total polyphenols were determined by using a calibration curve (\(R^2 = 0.99\)) with gallic acid (GAE).

The resistant starch was evaluated by following the international AOAC 2017.16 protocol, by using Megazyme kit. The determination principle consists of pasta sample digestion with α-amylase and amyloglucosidase for 120 min, followed by second digestion only with amyloglucosidase and spectrophotometric glucose quantification (at 510 nm) by
using glucose oxidase/peroxidase (GOPOD) reagent. All the chemical compounds were reported to product weight as it is.

2.5. Uncooked Pasta Color Evaluation

Uncooked pasta color in terms of luminosity ($L^*$), red or green nuance ($a^*$) and yellow or blue nuance ($b^*$) was evaluated by reflectance, in the CIE Lab system, on a Konica Minolta CR-400 (Tokyo, Japonia) colorimeter.

2.6. Pasta Cooking Behavior Determination

Pasta cooking loss and water absorption were determined gravimetrically according to the protocol described by Gimenez et al. [32], by boiling 10 g of pasta in 200 mL of water for the optimum cooking time.

2.7. Uncooked and Cooked Pasta Texture Evaluation

Uncooked pasta breaking force was measured on a Perten TVT-6700 texturometer (Perten Instruments, Hägersten, Sweden) equipped with an aluminum break rig set, at a test speed of 3 mm/s and a trigger force of 50 g [26].

Cooked pasta elasticity, chewiness and firmness were evaluated by means of double compression performed on one piece of sample, by using a Perten TVT-6700 equipment. A cylindric probe (35 mm diameter) was used for compression at 50% of sample height, at a test speed of 5.0 mm/s and a trigger force of 20 g [26].

2.8. Statistical Analysis

All of the determinations presented above were done at least in triplicate. The effect of grape peel flour on dough and pasta characteristics was evaluated by means of one-way ANOVA and Tukey test ($p < 0.05$), performed on XLSTAT for Excel 2021 version (Addinsoft, New York, NY, USA) software. The similarities and relations between characteristics were observed by applying Principal Component Analysis (PCA).

3. Results

3.1. Dough Visco-Elasticity

Wheat dough rheological properties in terms of elastic and viscous moduli were affected by grape peel flour incorporation. All the samples investigated presented a solid-like behavior since $G' > G''$, an increase of both moduli with frequency raise being obtained (Figure 3). The addition of grape peel flour led to increased $G'$ and $G''$ values compared to the control and as the amount was higher.

3.2. Texture of Dough

Dough texture knowledge is important for the prediction of its behavior during mixing and handling and could be affected by the incorporation of fiber-rich ingredients. Dough hardness was significantly higher ($p < 0.05$) as the amount of grape peel flour increased and compared to the control (Table 1).

Springiness varied from 99.55 to $99.75 \times 10^{-2}$, the highest value being obtained for GP6%, while the control sample exhibited the lowest springiness. Cohesiveness values registered slight increases with grape peel flour level increase and compared to the control. On the other hand, a proportional decrease of dough resilience was observed as the addition level of grape peel flour raised.

3.3. Pasta Chemical Compounds

The nutritional and functional value of pasta products can be improved by using ingredients with high bioactive properties. Pasta crude ash values varied from 0.52% for the control to 0.74% for GP6% sample (Table 2). An increasing trend proportional to the addition level was also observed in the case of crude fiber (Figure 4), the differences being significant ($p < 0.05$).
Table 1. Effects of grape peel flour on dough texture.

| Sample   | Hardness (N) | Resilience (Adim.) | Springiness × 10⁻² (Adim.) | Cohesiveness (Adim.) |
|----------|--------------|--------------------|-----------------------------|----------------------|
| Control  | 14.13 ± 0.62 f | 1.22 ± 0.06 abc    | 99.55 ± 0.03 b              | 0.36 ± 0.02 c        |
| GP1%     | 18.51 ± 0.18 e | 1.28 ± 0.01 a      | 99.57 ± 0.08 ab             | 0.39 ± 0.01 bc       |
| GP2%     | 24.71 ± 0.57 d | 1.25 ± 0.05 ab     | 99.60 ± 0.07 ab             | 0.39 ± 0.01 b        |
| GP3%     | 26.64 ± 0.36 c | 1.22 ± 0.01 abc    | 99.62 ± 0.08 ab             | 0.40 ± 0.00 b        |
| GP4%     | 28.21 ± 0.08 c | 1.18 ± 0.04 abc    | 99.66 ± 0.11 ab             | 0.41 ± 0.01 ab       |
| GP5%     | 32.11 ± 0.51 b | 1.18 ± 0.02 bc     | 99.73 ± 0.00 ab             | 0.42 ± 0.01 ab       |
| GP6%     | 38.77 ± 1.19 a | 1.14 ± 0.01 c      | 99.75 ± 0.91 a              | 0.43 ± 0.01 a        |

Each experiment was carried out in triplicate and data was reported as means ± standard deviation. Means in the same column with different letters are significantly different ($p < 0.05$).

Table 2. Effects of grape peel flour on pasta chemical compounds content.

| Sample   | Moisture (%) | Crude Ash (%) | Crude Fat (%) | Crude Protein (%) | Carbohydrates (%) |
|----------|--------------|---------------|---------------|-------------------|-------------------|
| Control  | 11.54 ± 0.03 a | 0.52 ± 0.04 d | 0.96 ± 0.02 c | 12.39 ± 0.18 a    | 72.11 ± 0.08 d    |
| GP1%     | 11.53 ± 0.03 a | 0.56 ± 0.04 cd| 0.97 ± 0.02 bc| 12.36 ± 0.18 a    | 74.56 ± 0.12 a    |
| GP2%     | 11.54 ± 0.02 a | 0.59 ± 0.02 bcd| 0.98 ± 0.01 abc| 12.32 ± 0.17 a    | 74.21 ± 0.08 ab   |
| GP3%     | 11.40 ± 0.17 a | 0.63 ± 0.04 abcd| 1.00 ± 0.04 abc| 12.29 ± 0.15 a    | 74.09 ± 0.20 b    |
| GP4%     | 11.42 ± 0.18 a | 0.66 ± 0.06 abc | 1.01 ± 0.06 abc | 12.26 ± 0.17 a    | 73.60 ± 0.26 c    |
| GP5%     | 11.48 ± 0.11 a | 0.70 ± 0.04 ab  | 1.02 ± 0.02 ab  | 12.22 ± 0.14 a    | 73.27 ± 0.21 cd   |
| GP6%     | 11.44 ± 0.16 a | 0.74 ± 0.04 a   | 1.04 ± 0.02 a   | 12.19 ± 0.16 a    | 73.10 ± 0.07 d    |

Each experiment was carried out in triplicate and data was reported as means ± standard deviation. Means in the same column with different letters are significantly different ($p < 0.05$).
Effects of grape peel flour addition on pasta total polyphenols content. Columns with different letters are significantly different ($p < 0.05$).

Crude fat, protein and moisture of pasta did not exert significant differences ($p > 0.05$) among samples. The carbohydrates content decreased with grape peel flour level raise, the values being higher compared to the control, as it can be observed in Table 2.

The incorporation of grape peel flour in common wheat pasta caused significant increase of total polyphenols (Figure 5) and resistant starch content (Figure 4) compared to the control and with the raise of the amount added, the variations being from 9.50 to 14.12 mg GAE/100 g and from 0.89 to 1.70%, respectively.

![Figure 4](image-url)  
**Figure 4.** Effects of grape peel flour addition on fiber and resistant starch contents of pasta. Columns with different letters are significantly different ($p < 0.05$): a–f for fiber content and x–w for resistant starch variation.

![Figure 5](image-url)  
**Figure 5.** Effects of grape peel flour addition on pasta total polyphenols content. Columns with different letters are significantly different ($p < 0.05$).
3.4. Uncooked Pasta Color

Color parameters of the final product depend on the components of dough, being influenced at the same time by the drying methods applied. The luminosity ($L^*$) of pasta samples supplemented with grape peel flour was smaller compared to the control and decreased with the addition level increase (Table 3). The red nuance of the samples containing grape peel flour, given by the positive values of $a^*$ parameter, showed significant ($p<0.05$) intensification as the amount raised, while the control and GP1% exhibited tendency to green nuance (negative values of $a^*$).

| Sample | Water Absorption (%) | Cooking Loss (%) | $L^*$ | $a^*$ | $b^*$ |
|--------|----------------------|------------------|-------|-------|-------|
| Control | 146.14 ± 5.33 $^a$ | 5.22 ± 0.12 $^{de}$ | 72.54 ± 0.17 $^a$ | −2.31 ± 0.20 $^c$ | 21.61 ± 0.24 $^a$ |
| GP1%   | 129.46 ± 3.55 $^c$ | 4.55 ± 0.30 $^e$ | 68.37 ± 0.09 $^b$ | −0.56 ± 0.02 $^d$ | 21.45 ± 0.64 $^a$ |
| GP2%   | 139.38 ± 1.37 $^{bc}$ | 5.43 ± 0.18 $^{cd}$ | 65.97 ± 1.11 $^c$ | 0.34 ± 0.06 $^c$ | 20.94 ± 0.48 $^a$ |
| GP3%   | 145.76 ± 5.45 $^{abc}$ | 5.72 ± 0.17 $^{cd}$ | 62.88 ± 0.52 $^d$ | 0.56 ± 0.02 $^d$ | 20.57 ± 0.49 $^{ab}$ |
| GP4%   | 147.02 ± 12.62 $^{ab}$ | 6.09 ± 0.31 $^c$ | 58.32 ± 0.28 $^e$ | 0.99 ± 0.07 $^b$ | 19.62 ± 0.26 $^{bc}$ |
| GP5%   | 149.46 ± 1.08 $^{ab}$ | 7.28 ± 0.36 $^b$ | 55.20 ± 0.50 $^f$ | 1.40 ± 0.04 $^a$ | 18.73 ± 0.23 $^{ed}$ |
| GP6%   | 155.91 ± 5.04 $^{ab}$ | 7.99 ± 0.14 $^a$ | 52.57 ± 0.31 $^e$ | 1.45 ± 0.26 $^a$ | 18.48 ± 0.23 $^d$ |

Each experiment was carried out in triplicate and data was reported as means ± standard deviation. Means in the same column with different letters are significantly different ($p<0.05$).

The yellow nuance of pasta suggested by the positive values of $b^*$ parameter presented a reduction trend as the level of grape peel flour was higher, the values ranging between 21.61 for the control sample and 18.48 for GP6% (Table 3).

3.5. Pasta Cooking Behavior

Pasta cooking behavior gives important quality characteristics which are given by the structure of dough and interactions between ingredients. Water absorption during boiling of pasta resulted in a proportional increase as the level of grape peel flour was higher, the obtained values being smaller compared to the control (Table 3). The amount of soluble solids lost during cooking (cooking loss) showed significant ($p<0.05$) increases as the addition level of grape peel flour raised.

### 3.6. Uncooked and Cooked Pasta Texture

Uncooked pasta breaking force could give valuable information about its resistance to handling and transport. The supplementation of common wheat pasta with grape peel flour led to the increase in breaking force proportional to the amount added, the values being higher compared to the control, except for GP1% which did not show significant difference (Table 4).

| Sample | Uncooked Pasta | Cooked Pasta |
|--------|----------------|--------------|
|        | Breaking Force (N) | Elasticity $\times 10^{-2}$ (adim.) | Chewiness (N) | Firmness (N) |
| Control | 41.26 ± 1.24 $^{cd}$ | 99.83 ± 0.07 $^a$ | 48.79 ± 2.19 $^a$ | 74.05 ± 0.91 $^a$ |
| GP1%   | 41.00 ± 1.01 $^d$ | 99.87 ± 0.01 $^a$ | 39.57 ± 0.09 $^b$ | 62.67 ± 1.85 $^b$ |
| GP2%   | 42.73 ± 1.95 $^{cd}$ | 99.87 ± 0.00 $^a$ | 38.98 ± 1.65 $^{bc}$ | 58.64 ± 0.26 $^{bc}$ |
| GP3%   | 44.32 ± 1.37 $^c$ | 99.91 ± 0.08 $^a$ | 36.29 ± 1.37 $^{bcd}$ | 57.40 ± 2.89 $^{bc}$ |
| GP4%   | 49.02 ± 0.15 $^b$ | 99.92 ± 0.07 $^a$ | 35.51 ± 0.99 $^{cd}$ | 56.43 ± 2.80 $^{cd}$ |
| GP5%   | 55.76 ± 0.54 $^a$ | 99.94 ± 0.06 $^a$ | 35.20 ± 1.17 $^d$ | 54.04 ± 1.83 $^{cd}$ |
| GP6%   | 58.46 ± 0.17 $^a$ | 99.96 ± 0.07 $^a$ | 34.11 ± 1.01 $^d$ | 51.67 ± 2.09 $^d$ |

Each experiment was carried out in triplicate and data was reported as means ± standard deviation. Means in the same column with different letters are significantly different ($p<0.05$).
Cooked pasta elasticity did not differ significantly \( (p < 0.05) \) among samples, a slight increase with the addition level of grape peel flour being noticed (Table 4). The chewiness property ranged between 48.79 N for the control and 34.11 N for GP6%, a decreasing trend being obtained as the amount was higher. Similar reduction tendency was observed in the case of firmness values which varied from 74.05 to 51.67 N.

### 3.7. Relations between Characteristics

Pearson’s correlations coefficients (Table 5) were obtained to evaluate the relations between the studied characteristics. Significant very strong correlations \( (p < 0.05) \) were obtained between cooking loss and crude ash \( (r = 0.92) \), crude fat \( (r = 0.92) \), crude protein \( (r = -0.92) \), crude fiber \( (r = 0.95) \). Color parameters \((L^*, a^*, b^*)\) were strongly correlated with the chemical composition of pasta \( (p < 0.05) \), except with moisture and carbohydrates, positive correlations being observed between \( L^* \) and crude protein \( (r = 0.99) \), \( a^* \) and crude ash \( (r = 0.92) \), crude fat \( (r = 0.92) \), crude fiber \( (r = 0.86) \), total polyphenols \( (r = 0.82) \) and resistant starch \( (r = -0.99) \), total polyphenols \( (r = -0.95) \) and resistant starch \( (r = -0.89) \), between \( a^* \) and crude protein \( (r = -0.99) \), between \( b^* \) and crude ash \( (r = -0.98) \), crude fat \( (r = -0.98) \), crude fiber \( (r = -0.99) \), total polyphenols \( (r = -0.98) \) and resistant starch \( (r = -0.82) \) content. A strong positive correlation significant at \( p < 0.05 \) was observed between total polyphenols content and resistant starch \( (r = 0.83) \). The total polyphenols and starch content were significantly correlated \( (p < 0.05) \) with the proximate composition, except moisture and carbohydrates.

Dough textural parameters (hardness, resilience, springiness and cohesiveness), uncooked pasta breaking force and cooked pasta textural characteristics (elasticity, chewiness and firmness) were strongly correlated with pasta chemical composition in terms of crude fat, protein, ash and fiber and with cooking loss (Table 5). Furthermore, pasta total polyphenols showed significant correlation \( (p < 0.05) \) with dough, uncooked and cooked pasta texture, except with pasta resilience. The resistant starch content was correlated at \( p < 0.05 \) significance level with dough hardness \( (r = 0.92) \), springiness \( (r = 0.83) \) and cohesiveness \( (r = 0.92) \), with pasta elasticity \( (r = 0.89) \), chewiness \( (r = -0.94) \) and firmness \( (r = -0.98) \). Dough hardness was significantly correlated \( (p < 0.05) \) with all uncooked and cooked pasta textural parameters.

The similarities and dissimilarities between characteristics and samples were evaluated by means of Principal Component Analysis (PCA), the results being presented in Figure 6. The first principal component (PC1) explained 79.26% of data variance, the second principal component explained 16.12% of the variance, both summing 95.38% of the total variance. PC1 was associated with cooking, loss, pasta breaking force, total polyphenols, crude fiber, springiness, crude fat, crude ash, dough hardness, pasta elasticity, dough cohesiveness, resistant starch, color parameters, pasta firmness and chewiness, crude protein, while PC2 was associated with water absorption and carbohydrates content.

The moisture content of pasta exerts less influence on data variation, as it is suggested by its position closer to the origin of the graphic (Figure 6). Pasta samples which contained grape peel flour added were in opposition to the control which was associated with firmness and chewiness parameters. It can be observed that pasta with the highest grape peel flour levels (GP5%, GP6%) were associated with the fiber and total polyphenols contents, as expected.
Table 5. Correlations between variables.

| Variables   | WA  | CL  | L*  | a*  | b*  | Moisture | Crude Ash | Crude Fat | Crude Protein | Crude Fiber | Carbohydr. | TP  | RS  | Hardness | Resilience | Springiness | Cohesiveness | Breaking f. | Elasticity | Chewiness | Firmness |
|-------------|-----|-----|-----|-----|-----|----------|-----------|-----------|--------------|-------------|-------------|-----|-----|----------|------------|-------------|--------------|-------------|----------|-----------|----------|
| WA          | 1.00| 0.93| −0.21| −0.11| −0.34| −0.23| 0.24      | 0.24      | −0.24        | 0.36        | −0.42       | 0.42| −0.06| 0.20      | −0.17      | 0.30         | 0.02         | 0.41       | 0.17      | 0.25      | 0.16      |
| CL          | 1.00| 0.91| 0.72 | −0.56| −0.50| 0.52| 0.92      | 0.92      | −0.92        | 0.96        | −0.79       | 0.79| 0.01| −0.95     | −0.89      | −0.83        | −0.98        | −0.98      | −0.95     | −0.98     | 0.87      | 0.90      |
| L*          | 1.00| 0.92| 0.98| 0.66 | −0.59| 0.99| 0.99      | 0.91      | −0.95        | 0.96        | 0.96        | 0.96| 0.96| 0.94      | 0.99       | 0.90         | 0.93         | 0.98       | 0.98      | 0.98      | 0.98      | 0.98      |
| a*          | 1.00| 0.85| −0.65| 0.52 | 0.92| −0.92| 0.92      | 0.86      | 0.92         | 0.92        | −0.11       | 0.24| 0.24| 0.24      | 0.24       | 0.24         | 0.24         | 0.24       | 0.24      | 0.24      | 0.24      | 0.24      |
| Carbohydr.  | 1.00| 0.58| −0.98| 0.98 | 0.98| 0.98| 0.98      | 0.98      | 0.98         | 0.98        | 0.98        | 0.98| 0.98| 0.98      | 0.98       | 0.98         | 0.98         | 0.98       | 0.98      | 0.98      | 0.98      | 0.98      |
| TP          | 1.00| 0.85| 0.99| 0.99 | 0.99| 0.99| 0.99      | 0.99      | 0.99         | 0.99        | 0.99        | 0.99| 0.99| 0.99      | 0.99       | 0.99         | 0.99         | 0.99       | 0.99      | 0.99      | 0.99      | 0.99      |
| RS          | 1.00| 0.99| 0.99| 0.99 | 0.99| 0.99| 0.99      | 0.99      | 0.99         | 0.99        | 0.99        | 0.99| 0.99| 0.99      | 0.99       | 0.99         | 0.99         | 0.99       | 0.99      | 0.99      | 0.99      | 0.99      |

WA—water absorption, CL—cooking loss, TP—total polyphenols, RS—resistant starch. Values in bold are different from 0 with a significance level of 95%.
4. Discussion

Wheat pasta dough and final product properties were proved to be significantly affected by grape peel flour inclusion. The dynamic rheological properties could provide information about the physical properties of dough, but also about the adhesiveness, kneading behavior, elasticity and hardness [23]. The elastic and viscous moduli of dough increased gradually as the addition level was higher, a possible cause being represented by the presence of hydroxyl groups from phenolic compounds from grape peels [33]. Protein–polyphenol interactions could change protein structure, resulting in different quality and functional characteristics of pasta. Some phenolic compounds could have been contributed to the formation of new complexes with gluten proteins, strengthening dough structure, as stated by Zhang et al. [34]. These authors demonstrated that the addition of tannic acid in wheat dough caused dough strengthening and elasticity increase, showing also the raise of sulfhydryl groups and the depletion of free amino groups in dough [34]. They explained these results by the formation of linkages between the tannic acid and gluten proteins, underlying that not only the disulfide bonds are responsible for dough strength, but also the complexes formed by polyphenols with flour proteins [34]. Thus, these results, along with those obtained by Meral and Dogan [33] for wheat dough with grape seeds, confirmed our findings. Chen et al. [35] revealed that the incorporation of 1% grape seeds flour in wheat noodles resulted in positive effects of final product quality and protein stability, obtaining at the same time an increase of free sulfhydryl groups which were proved to reduce dough strength. Thus, it can be concluded that the effects of grape peel flour on dough may not be assigned to the development of disulfide bonds, but possibly to the formation of non-covalent bonds such as hydrogen bonds, hydrophobic bonds and ionic bonds [35]. \( G' \) and \( G'' \) increase was also supported by the raise of dough hardness proportional to the addition of grape peel flour level increase, significant correlation \( (p < 0.05) \) being obtained with the chemical composition of pasta, including proteins, fibers and polyphenols content. Dough resilience decreased as the amount of grape peel flour raised, while cohesiveness showed and opposite trend. Dough textural parameters are strongly influenced by ingredients particle size, as previously demonstrated [7,36,37]. The use of small particle size of grape peel flour (<180 µm) could have been contributed to these changes in dough texture since these particles have greater contact surface and consequently could absorb more water.

![Figure 6. Principal Component Analysis (PCA) bi-plot.](image)
Furthermore, the chemical composition of the added ingredient had a major impact on dough texture which is given by the interactions between proteins, starch, lipids, fibers and sugars. Grape peel sugars could have a great contribution to dough cohesiveness increase since they could form bridges between starch and protein molecules [38]. Resilience was found to be directly influenced by protein quality, presence of soluble fiber and water availability [39]. Thus, the competition of gluten proteins with grape peel particles for water could have been a possible explanation of dough resilience decrease.

Pasta proximate composition was influenced by grape peel flour incorporation, significant changes in crude ash, crude fat and carbohydrates being observed. The intake of nutrients of grape peel flour determined the increase of final product ash and fat, while the protein content showed a slight decrease. Similar reduction in protein content and increase in ash was reported for durum wheat pasta enriched with apple flour which could be due to the dilution effect of wheat protein [40]. The carbohydrates content decrease was in line with the results reported by Bender et al. [41] which showed that the addition of grape skin lowered muffins carbohydrates values. One of the most important contribution of grape peel flour is to the raise of pasta fiber content, total polyphenols content and resistant starch. It is well known that grape peels are rich sources of soluble and insoluble dietary fibers and polyphenols such as flavonols, hydroxybenzoic, hydroxycinnamic acids, flavanols, tyrosol and condensed tannins [42,43]. The strong correlation ($r = 0.83$, $p < 0.05$) obtained between polyphenols and resistant starch content support the hypothesis of starch digestibility changes caused by polyphenols presence. Rocchetti et al. [44] demonstrated that polyphenols play an important role in the rate and the extent of starch digestion. Resistant starch formation could be promoted by the presence of polyphenols [45], the interactions between starch and polyphenols resulting in insoluble complexes development [46]. Furthermore, the phenolic compounds presence can raise resistant starch content due to the appearance of non-covalent phenolic/starch interactions and/or to the inhibition of digestive enzymes [44,45].

Total polyphenols and fiber content were correlated to pasta cooking loss increase ($r = 0.99$ and $r = 0.95$ respectively at $p < 0.05$). Similar raise was reported by Bustos et al. [47] for pasta supplemented with berry flour, being probably related to the gluten dilution effect and to the pectin presence which can contribute to the leaching of components in the boiling water. Grape peel flour gradually increased pasta water absorption which could be due to the affinity of the ingredient added for water [19]. Dietary fiber comprises cellulose, hemi-cellulose, pectin and others, pectin and galactomannan being proved to have higher water-holding capacity compared to cellulose [48]. Grape peels contain pectin [49] which can explain the increase in water absorption of pasta due to the formation of hydrogen linkages between water and hydroxyl groups of these polysaccharides. Pasta color was significantly influenced ($p < 0.05$) by grape peel flour incorporation, leading to lower luminosity and yellow nuance and higher red nuance as the level increased, similar findings being reported by Sant’Anna et al. [50] for pasta enriched with grape marc. These changes in color properties could be due to the presence of natural pigments in the ingredient added.

Uncooked pasta breaking force was significantly correlated ($p < 0.05$) to the chemical composition and to the texture of dough. The increasing trend of pasta breaking force could be related to the presence of polyphenols which may exert a strengthening effect, fact suggested also by the high correlation obtained ($r = 97$, $p < 0.05$). Similar tendency and correlation were reported by Šporin et al. [51] when grape pomace was incorporated in wheat dough. Cooked pasta chewiness and firmness decreased as the amount of grape peel flour was higher and compared to the control, while elasticity slightly increased. Similar raise for pasta elasticity was reported by Pasqualone et al. [52] for pasta supplemented with tomato flour. Chen et al. [35] reported a gradual decreasing trend of wheat gluten noodles when more than 1% grape seeds were added. Pasta firmness is determined by starch grains hydration during boiling and by the embedding of gelatinized starch grains in a network of partially denatured protein [53]. Polyphenols from grape peel can interact
with starch, disturbing starch hydration and gelatinization and changing protein-starch matrix properties which led to hardness reduction [54].

5. Conclusions
Grape peel as a by-product resulted from wine processing are important sources of fibers and polyphenols that can give value added to the food products in which they can be incorporated. Pasta is a suitable matrix in which such ingredients could be incorporated to potentiate the nutritional and functional value. Grape peel flour addition in common wheat pasta resulted in higher visco-elastic moduli proportional to the level increase. Dough texture was significantly influenced by grape peel flour, leading to hardness, springiness and cohesiveness increase. The chemical composition of pasta showed significant increases of crude ash, crude protein and crude fat, while the protein content decreased as the addition level of grape peel flour raised. The purpose of this study of increasing the functionality of wheat pasta was achieved and confirmed by the significant higher fiber, total polyphenols and resistant starch proportional to the level raise. The gluten dilution effect was observed by the higher amount of soluble solids leached from pasta in the boiling water, with water absorption registering an increasing trend. Grape peel flour exhibited positive effects on pasta breaking force and elasticity by growing their value proportional to the level added, while cooked pasta chewiness and firmness decreased. Pasta luminosity and the yellow nuance were reduced as the amount of grape peel flour was higher, and the red nuance intensified due to the intake of pigments. The variations of textural and color parameters of dough and pasta were related to the chemical composition of the samples, significant correlations \( p < 0.05 \) being observed. Thus, an addition level of about 5% grape peel flour would give significant pasta functional value improvement, while keeping acceptable quality parameters. The obtained results can contribute to the knowledge of grape peel’s effects on dough and pasta properties, making up a source of inspiration for processors interested in functional products development.

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