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# Characterization and possible valorization of grape skin in extruded crisps

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ABSTRACT

Grape skin byproduct valorization in extrudates for human nutrition is a great opportunity with many health, environmental, and economic benefits. This paper explored the impact of red and white grape skins on corn flour and extruded crisp quality. Flour mixtures composition was assessed along with extruded products' properties in terms of digestibility, polyphenols, texture, physical, and functional properties. Grape skin increased ($p < 0.05$) the content of nutrients (from 7.20 to 9.53 % protein, from 1.32 to 3.36 % fat, from 6.74 to 28.10 % for fiber) in the flour mixtures and changed the color depending on the addition level and grape skin type. Final product quality was affected significantly ($p < 0.05$) by grape skin: the expansion index (from 3.70 to 2.68), pore size, and functional properties decreased as the level was higher. White grape skin decreased ($p < 0.05$) the texture parameters (5.82 to 3.63N/s for crispness), while the opposite trend was observed for the red type (3.82 to 6.20N/s for crispness). Grape skin came with an intake of polyphenols like myricetin, p-coumaric acid, and determined significant changes ($p < 0.05$) in starch digestibility. Acceptable scores for the sensory texture parameters were obtained even at 40 % red grape skin content, but considering the characteristics evaluated, an addition level of 30 % would be recommended. The novelty lies in the complete and applied approach to the valorization of high amounts of grape skin (up to 40 %) to improve the nutritional and functional properties of expanded corn crisps, providing concrete data for optimizing the process on an industrial scale.

## 1. Introduction

The food industry is in continuous development and seeks to meet the increasingly diversified demands of consumers who are more aware of the need to modify their lifestyle behavior (Hassoun et al., 2022). Consumers want more and more foodstuffs with health promoting ingredients, nutritious and functional foods, and are interested in healthy snacks, which are meant as practical and easy to consume products (Marcos et al., 2023; Ungureanu et al., 2024). Functional foods, recognized for their biologically active properties offering nutritional benefits, are increasingly acknowledged for their positive impact on health (Abedinia et al., 2025).

The incorporation of food by products into existing food manufacturing processes is a significant opportunity in the context of circular economy and waste prevention. The development of high nutritional value snacks with beneficial effects on consumer health by using innovative flours such as those obtained from grape by products could provide the necessary nutrients, raising their nutritional value. One of the grape by products generated during the winemaking process is represented by grape skin which count approximately 50 % of the grape pomace; the ratio between skins and seeds can vary depending on the grape variety and cultivation conditions (Iuga and Mironeasa, 2020; Mironeasa et al., 2019). Some studies revealed that grape skin has been proposed as a food ingredient owing to its nutritional value and functional properties due to the presence of high levels of dietary fiber, phenols, flavonoids, and other antioxidant substances (Beres et al., 2016; Bordiga et al., 2019; Difonzo et al., 2023). The grape skins are particularly interesting for their dietary fiber which prevents obesity, reduces blood cholesterol levels, and improves intestinal transit of stool (Soliman, 2019). Their content varied up to almost 60 % of dry matter dominated up to 98.5 % by insoluble dietary fiber (Deng et al., 2011). The grape skins contain also from 5 % to 12 % proteins, from 2 % to 8 % ash, and from 1 % to >70 % soluble sugars, depending on the winery technology, if the pomace is fermented or not (Deng et al., 2011; Iuga

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and Mironeasa, 2020). In addition to dietary fiber, the grape skin matrix contains considerable percentages of phenolic fractions which impart its antioxidant properties, being responsible for protective properties against various chronic diseases. Higher amounts of phenolic compounds and dietary fiber were reported for red skins compared with white skins (Dwyer et al., 2014). In another study, it was found that the white grape varieties under evaluation yielded higher values for total phenolics and proanthocyanidins compared to red varieties, even though the red grape marcs contained residual anthocyanins and other coloring matter (de la Cerda-Carrasco et al., 2015).

Extrusion technology is often used for the development of ready-to-eat products such as snacks. As a process with high productivity and versatility which is performed at a high pressure and temperature, it offers the possibility to add value to the by products like grape skins, by incorporating them in new products such as extruded crisps. The chemical and structural transformations of food materials and reactions during the thermo-mechanically extrusion-cooked provide changes in the physicochemical and textural properties of the final product (Asif et al., 2024). Moreover, in the extrusion process, unwanted enzymes and some anti-nutritional factors are inactivated, and the final product is sterilized and retains its natural color and flavor (Fellows, 2022; Petrović et al., 2024). However, the development of palatable extruded crisps with functional properties represents a food engineering challenge because a high level of fiber can determine the low expansion capability of polymer matrices containing a large quantity of fiber (Sozer and Poutanen, 2013). The oligosaccharides present in grape skin as a result of the degradation of berry cell wall polysaccharides (Bordiga et al., 2019) can improve the expansion index and provide additional functional properties, acting as nutrients for colonic microflora (Bordiga et al., 2019; Sozer and Poutanen, 2013). It has been demonstrated that the expansion ratio and the extrudates' capacity to absorb water is enhanced by some polysaccharide, depending on the type and degree of methylation (Xie et al., 2021). On the other hand, the polysaccharide-lipid complexes formed during extrusion contribute to the insoluble fiber fraction (Gualberto et al., 1997; Torres-Aguilar et al., 2023) and increase the insoluble fiber by reducing starch digestibility in nutritious crisps. This change is desirable, but the consumer acceptability of the extruded crisps needs to be taken into consideration because it depends on many quality features such as appearance, structure, texture, taste, color, and flavor. The structural properties are indices of the extent of puffing and they are of essential importance since they characterize the texture and quality of expanded products by controlling their taste and appearance (Hagenimana et al., 2006; van der Sman et al., 2021). When a high content of dietary fiber is added in extrudates, they can cause lower expansion and finite products with undesired characteristics (Adibah et al., 2024; Stojceska et al., 2010). Expansion is desirable for successful product development and it is also associated with other important properties, such as crispness, water absorption, etc. (Adibah et al., 2024; Bisharat et al., 2013).

There is a scarcity of studies about the highest percentage of grape skins that can be incorporated in maize flour to produce the functional extruded crisps desired by consumers. For this reason, this investigation aimed to exploit the potential of grape skins from white and red grape pomace in the development of innovative extruded crisps by valorization in a considerable amount of these by products. The effect of partial maize flour substitution with these grape skins flour was evaluated by investigating the proximate composition, color, and amino acid content of the flour mixtures. In addition, the research focused on the final product quality, expansion, and functional properties, Fourier transform infrared spectroscopy (FT-IR) molecular characteristics, starch digestibility, polyphenols, color, microstructure, mechanical and, sensory texture. The results presented in this study will provide a base for the production of extruded crisps with grape skin, as well as some insights into the viability of extrusion for the development of nutraceutical crisps by using this by product generated by the winemaking industry.

## 2. Materials and methods

The following chemicals were used in this study: copper sulfate pentahydrate 99.9 % (CAS 7758–98–7), potassium sulfate 99 % (CAS 7778–80–5), petroleum ether 99 % (CAS 8032–32–4), Megazyme kit for fiber determination (K-TDFR-200a 04/17; Megazyme, Bray, Ireland), hydrochloric acid 0.1 N (CAS 7647–01–0), acetonitrile 99.99 % (CAS 75–05–8), o-phthalaldehyde 99 % (CAS 643–79–8), 9-fluorenylmethyl chloroformate 99 % (CAS 28,920–43–6), disodium hydrogen phosphate 99 % (CAS 10,028–24–7), disodium tetraborate 99 % (CAS 1330–43–4), methanol 99.9 % (CAS 67–56–1), starch Megazyme kit (K-DSTRS; Megazyme, Bray, Ireland), acetone 99 % (CAS 67–64–1), and acetic acid 99.8 % (CAS 64–19–7).

### 2.1. Ingredients preparation and characterization

The red and white grape pomace was acquired from the Iaşi Research and Development Center for Viticulture and Vinification. The Iași area has a pronounced temperate continental climate, characterized by predominantly dry summers and high temperatures that can reach an absolute maximum of +40 °C (SCDPI, 2022). Global solar radiation averages 116 kcal/cm$^2$ annually, with an uneven distribution (SCDPI, 2022). Precipitation has a multi-annual average of 531.7 mm, but its distribution is uneven. Dominant air mass movements are more frequent from W-SE and SW, especially in winter, and from W-SW and NW, particularly in summer. The plantations are located on a mesorelief with a slightly inclined plateau and primarily feature cambic chernozem soils with good natural drainage. The parent rock is loessoid clay (SCDPI, 2022).

Maize was bought from a Romanian local producer. After drying in a convection oven ZRD-A5055 (Zhicheng Analysis Instrument, Shanghai, China) at 50 ± 2 °C until humidity was <10 %, the seeds were manually removed from the pomaces and the resulting skin was grounded in a laboratory mill (Perten 3100, Perten Instruments, Huddinge, Sweden). To obtain a uniform powder, grape skin was sieved by using a mesh <0.2 mm. Flour mixtures were obtained by mixing maize flour with white (GSW) or red (GSR) grape skin in various proportions (10–40 %), and the maize flour without any addition was considered the control. Flour moisture conditioning was made in a mixer (Bosch MFQ3520, Gerlinger, Germany) to achieve a value of 15 ± 0.1 % (v/w).

#### 2.1.2. Analysis of the chemical profile

The chemical profile of the flour mixtures and of the ingredients in terms of ash, protein, fat, carbohydrates, and dietary fiber was assessed according to the International and Romanian standard methods: SR ISO 2171/2010, SR EN ISO 20,483/2007, SR 91/2007, the carbohydrates were calculated by difference, and the total dietary fiber was measured with a Megazyme kit (K-TDFR-200a 04/17) according to the AACC 32–05.01 protocol.

#### 2.1.3. Amino acid determination of the mixtures

A HPLC system (Shimadzu LC40-PDA-40 system) was employed to quantify the amounts of amino acids in the flour mixtures. Ground samples (1 ± 0.001 g) were suspended in HCL 0.1 N (g mL), and centrifuged for 20 min at 4000 rpm at 4 °C. After filtration (0.45 μm pores), the liquid was deproteinized with acetonitrile and filtered again (Igual et al., 2021). The derivatization of the sample was made in agreement with the Agilent - Amino Acid Analysis protocol, using o-phthalaldehyde and 9-fluorenylmethyl chloroformate. A LC column 4.6 × 100 mm was used for separation, while the quantitative determination of the amino acids was made on a Shimadzu LC40-PDA-40 system (Shimadzu, Japan), at a wavelength of 338 nm (bandwidth 10 nm). The mobile phase A was composed of 10 mM $Na_2HPO_4$ and 10 mM $Na_2B4O_7$ at pH 8.2, and the mobile phase B was composed of acetonitrile: methanol: water (45:45:10 v:v). The operation conditions were: gradient at min 0 – B 2 %, min 0.35 – B 2 %, min 13.4 – B 57 %, min 13.5

– B 100 %, min 15.7 – B 100 %, min 15.8 – B 2 %, min 18 – end. The flow rate was established at 1.5 mL/min.

#### 2.1.4. Hydration properties of the ingredients

Water absorption capacity (WAC) was determined according to the protocol described by Zhu et al. (2014). Grape skin or maize samples were stirred with distilled water (1:30 w:v) and it was left for 18 h at room temperature. After centrifugation at 3000 rpm for 20 min the supernatant was removed and the solid was dried for 2 h at 105 ± 2 °C. WAC (g/g) was determined gravimetrically and represented the difference between the wet sample weight and dry sample weight divided by the dry sample weight.

Swelling capacity (SC), was determined also by following the method of Zhu et al. (2014). An amount of 0.5 ± 0.001 g of grape skin or maize flour was stirred with 15 ± 0.1 mL distilled water and equilibrated for 18 h at room temperature. Then, the final volume of the sample was recorded, and SC (mL/g) was determined as the volume of the sample per gram of initial sample weight.

#### 2.1.5. Color of the mixtures

The flour samples were put in transparent petri dishes and the surface was uniformized. The Lightness (L*), green or red nuance (a*), and the yellow or blue nuance (b)* were measured (Khajeh et al., 2025) with a CR-400 device (Konica Minolta, Tokyo, Japan). The chromameter was first calibrated using a white standard plate.

### 2.2. Extrusion experiments and determination of the final product characteristics

A laboratory single-screw extruder (Kompakt extruder KE 19/25, Brabender, Duisburg, Germany) was used to obtain the extruded products (Figure S1, supplementary material). The barrel diameter was 19 mm, the length diameter ratio 25:1, and it was used a nozzle with 2 mm diameter. The feeding rate was kept constant at 24 rpm and the screw speed was 150 ± 1 % rpm. The temperatures in the four steps were 50, 95, 175, and 180 °C, with a tolerance of ± 1.2 °C respectively. The extruded crisps were cooled at room temperature and equilibrated for 16 h, then they were cut into pieces and stored in polyethylene bags.

#### 2.2.1. Analysis of expansion characteristics

The expansion ratio (ER) of the expanded snacks was defined as the ratio of the diameter of the extrudate to the diameter of the die (Boluk et al., 2010; Chiu et al., 2013); 20 randomly selected segments for each sample were measured using a digital caliper (Model Series 500, Mitutoyo, Japan), and the average value was reported.

Bulk density (BD) was measured by employing the displacement protocol (Adibah et al., 2024; Yu et al., 2012) Extruded snacks were cut into strands of 25 ± 0.1 mm in length, then 15 pieces were weighed ($M$, g) and placed in a 100 mL cylinder; then mustard seeds were added to fill up the cylinder. The extruded snacks were then eliminated, and the volume of the mustard seeds was recorded ($V$, mL). The analysis was done in triplicate. Bulk density (g/mL) was calculated as the ratio between $M$ and the difference between 100 and $V$.

The porosity of the extruded snacks was calculated as the ratio between the difference in bulk volume and apparent volume, and bulk volume (Rathod and Annapure, 2017). For porosity determinations, 15 pieces of products were placed in a 250 mL cylinder and filled with mustard seeds. The volume of mustard seeds without snacks was also noted and the difference is the bulk volume. After that, the same snacks were ground into a fine powder, and the volume of ground snacks was measured in the same cylinder which represented the apparent volume. The difference between the bulk volume and apparent volume is an estimation of the internal void volume, allowing for the appreciation of the material's porosity (Rathod and Annapure, 2017).

#### 2.2.2. Water absorption capacity and water solubility indices

Water absorption index (WAI), defined as the quantity of water that remains bound to the hydrated fiber following the application of an external force, pressure, or centrifugation, was estimated as previously described by Ratod et al. (Rathod and Annapure, 2017). Extrudates were ground to obtain a powder and passed through the 250 μm sieve for uniform-size distribution. An amount of 2.5 g extrudates powder was suspended in 25 mL water at room temperature for 30 min, with intermediate stirring, and then centrifuged at 3000 rpm for 15 min. The hydrated residue was weighed after supernatant removal. The supernatant was decanted into the reweighed evaporating dish and water was evaporated till constant weight to get dry solids. WAI (g/g) was calculated as the weight of hydrated residue per unit weight of original dry solids. The water solubility index (WSI) represents the weight of dry solids in the supernatant expressed as a percentage of the original weight of the sample.

#### 2.2.3. Molecular characterization (FTIR) of extrudates

The molecular characteristics of the extruded crisps were investigated by Fourier transform infrared (FTIR) spectroscopy using a Thermo Scientific Nicolet iS20 (Waltham, MA, USA) spectrophotometer with attenuated total reflection (ATR). The spectra were collected from 650 to 4000 $cm^{-1}$, at a resolution of 4 $cm^{-1}$ and 32 scans. The molecular characteristics were established according to the existing literature (Nogales-Bueno et al., 2017; Reinaldo et al., 2021) and by using OMNIC software (9.9.549 version, Termo Fisher Scientifc, Waltham, MA, USA).

#### 2.2.4. Starch digestion rate index

Total starch content was determined with a Megazyme kit (K-DSTRS; Megazyme, Bray, Ireland), according to the method provided by the manufacturer for the kit (Batariuc et al., 2023). The resistant and rapidly digestible starch were determined by using the spectrophotometric method, and the starch digestion index (SDRI) was calculated as the ratio between RDS and total starch. Total starch was calculated as the sum of total digestible starch and resistant starch.

#### 2.2.5. Polyphenols content

For extraction 1 ± 0.001 g of sample was mixed with 10 ± 0.01 mL solvent (70 % acetone+28 % water+2 % acetic acid (v/v/v)) and ultrasonicated for 60 min at 45 Hz, then the mix was centrifuged and the supernatant was collected. The extraction was repeated twice and the supernatants were combined.

For individual phenolics separation and quantification, the phenolic extracts were analyzed using a High Performance Liquid Chromatography (HPLC) (Shimadzu, Kyoto, Japan) system equipped with a LC-20 CE liquid chromatograph, SIL-20A autosampler, CTO-20AC column oven, and a SPD-M-20A diode array detector, as previously reported (Oroian et al., 2020). The separation was performed on a Phenomenex Kinetex® 2.6 μm Biphenyl 100 Å HPLC Column 150 × 4.6 mm, thermostated at 25 °C. It used an injection volume of 10 μL, and the solvents used were 0.1 % acetic acid in water (solvent A) and acetonitrile (solvent B). The gradients were the following: beginning with 100 % A and installing a gradient to achieve 5 % B at 6.66 min, 40 % B at 66.6 min, and 80 % B at 74 min, based on a previously described protocol (Oroian et al., 2020) . The solvent flow rate was set to 1 mL/min. The polyphenols were identified according to the retention times of standard solutions and the quantification was obtained by the absorbance registered in the chromatograms relative to external standards, at 320 nm for p-coumaric acid, rosmarinic acid, myricetin, luteolin, and quercetin. The regression coefficients of the standard calibration curves were $R^2 > 0.99$.

#### 2.2.6. Color of the extrudates

Extruded crisps samples were ground before analysis. The color characteristics of the extruded crisps were evaluated by following the method described in Section 2.1.5. The browning index was calculated by using Eq. (1):

$$BI = \frac{[100(X - 0.31)]}{0.172} \quad (1)$$

where BI – brown index, X – constant, and $X = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}$ where L* - lightness, a* - red or green nuance, b* - yellow or blue nuance.

#### 2.2.7. Texture properties analysis

The texture of the extruded crisps was investigated by using a TVT 6700 texturometer (Perten Instruments, Hägersten, Sweden). A single cycle compression test was applied to a piece of sample of 1 cm length, at a speed test of 1 mm/s and a compression of 50 % by using a 25 mm cylinder probe. The cutting force was determined by using a cutting blade with a V shape, at a test speed of 1 mm/s, perpendicular to the sample of 4 cm length. The crispness was determined as the slope of the first peak. A puncture test was performed on a sample with a 1 ± 0.01 cm length by using a puncture cylinder probe with a 3 mm diameter, at a speed test of 1 mm/s. The data was processed by using TexCalc software.

#### 2.2.8. Texture sensory analysis

Snacks hardness, crunchiness, fracturability, chewiness. and adhesiveness were evaluated by 65 panelists. For the sensory analysis test, ethical clearance was granted for the study by the research ethics committee of Stefan cel Mare University of Suceava, Romania. The panelists were students from the Food Engineering Faculty, and informed consent was obtained before evaluation. The judges were instructed to eat and swallow each coded sample of the extruded snack and rate the intensity of each attribute on a 90-points scale (according to ISO 8589:2007). The judges were provided with mineral water to clean their mouths between tasting.

#### 2.2.9. Microscopic images

The microscopic images of the extruded crisps were assessed using a Hitachi SU-70 Field Emission Scanning Electron Microscope (FE-SEM). The samples of 3 to 5 mm in length were fixed with a double-sided adhesive carbon-based tape and coated with platinum before analysis. The images were achieved at 15–20 kV and a magnification of 30x, according to a modified protocol described by Boluk et al. (2010).

### 2.3. Statistical analysis

All the analyses were carried out at least in triplicates and the results are presented as the mean ± standard deviation. Tukey test was used ($\alpha = 0.05$) to check the significant differences between treatments using XL Stat software (2023 version). The relationships between the studied variables were evaluated through Principal Component Analysis.

## 3. Results and discussion

### 3.1. Characterization of the mixes and ingredients

#### 3.1.1. Physico-chemical characteristics of the ingredients

The chemical, color, and functional properties of the ingredients (maize, grape skin white, and grape skin red) are presented in supplementary material (Table S1). Maize flour is rich in carbohydrates, while grape skin has a higher content of protein, fat, ash, and fiber. Compared to GSR, GSW presented lower WRC, protein, fat, ash, and fiber content. Ahmad et al. (2024) reported a fat content of maize flour of 2.50 %, ash 0.58 %, and protein content of 14.05 %. The differences between our study and those reported by Ahmad et al. (2024) regarding maize proximate composition may be related to the maize variety and cultivation conditions. The chemical composition of grape skin is close to the one reported by Difonzo et al. (2023) for grape skin powder (5.97 % for lipids, 11.13 % for proteins, 52.16 % for total dietary fiber and 17.81 % carbohydrates). WRC values for grape GSW and GSR are in agreement with those reported by González-Centeno et al. (2010) for treated grape pomace powder. WRC and SC are greatly influenced by dietary fiber content and structure (Santos et al., 2022). Grape skin color is given by the content of polyphenols (anthocyanins for red varieties) and depends on the climatic conditions and maturity level (Kwiatkowski et al., 2020).

#### 3.1.2. Characteristics of the mixtures

*3.1.2.1. Chemical profile.* The chemical profile in terms of protein, fat, ash, carbohydrates, and TDF of the maize-grape skin mixtures is presented in Table 1. The addition of GS determined the increase of all the parameters mentioned, except the carbohydrates content which decreased proportionally with the addition level. Red skin-containing samples exhibited higher values for protein, fat, ash, and TDF compared to the white ones which is explained by the greater abundance of these nutrients in GSR compared to GSW. Bello & Esin (2023) also obtained higher ash, fiber, and fat content of maize flour blends when coconut pomace flour was added. An increase in fiber and fat content was reported (Singha and Muthukumarappan, 2018) in corn-soy flour blends proportional to the amount of apple pomace flour addition. Biscuits and cereal bars enhanced with grape pomace exhibited also higher fiber, fat, and ash content and lower carbohydrates values compared to the control, as reported by Antoniolli et al. (2024).

*3.1.2.2. Amino acids.* Protein quality is typically assessed by the quantity and composition of its essential amino acids (Amiri et al., 2024). The main essential amino acids found in the flour mixtures included methionine, isoleucine, leucine, lysine, and threonine (Fig. 1). GSR samples presented higher amounts of methionine compared to GSW and the control. No significant differences ($p > 0.05$) among the different addition levels were observed for the essential amino acids content, except methionine in GSW samples which increased for GSW20. It was stated that the amino acid profile of grape by products is close to the one of cereals (Antoniolli et al., 2024) and this can explain the results of the present study. Among the non-essential amino acids, aspartic acid, glutamic acid, arginine, alanine, tyrosine, and norvaline were found in most of the samples studied (Fig. 1). GSW samples presented lower aspartic acid content compared with the control and GSR, and the values increased significantly at 30 and 40 % addition levels. Chikwanha et al. (2018) observed that the content of aspartic acid in S. blanc grape pomace (white) was lower compared to Pinotage grape pomace (red), which is in agreement with the results of our study. GSR samples had significant amounts of glycine which was less present in Control and GSW flours (Fig. 1). The highest alanine concentrations were observed for GSW10 and GSR20. Tyrosine was more abundant in the enriched samples compared to the Control. Buzzanca et al. (2024) investigated

**Table 1**
Chemical profile of the mixtures (w/w sample weight).

| Sample | Protein (%) | Fat (%) | Ash (%) | Carbohydrates (%) | TDF (%) |
|---|---|---|---|---|---|
| Control | 7.20 ±0.06 [f] | 1.32 ±0.01 [i] | 0.60 ±0.01 [i] | 78.40±0.10 [a] | 6.74±0.11 [e] |
| GSW10 | 7.63 ±0.07 [e] | 1.74 ±0.02 [h] | 0.92 ±0.02 [h] | 77.42±0.11 [ab] | 11.33 ±0.09 [de] |
| GSW20 | 8.07 ±0.08 [d] | 2.15 ±0.02 [f] | 1.24 ±0.02 [f] | 76.44±0.13 [bc] | 15.91 ±0.07 [cd] |
| GSW30 | 8.51 ±0.08 [c] | 2.57 ±0.03 [d] | 1.56 ±0.03 [e] | 75.45±0.14 [cd] | 20.50 ±0.05 [bc] |
| GSW40 | 8.95 ±0.09 [b] | 2.99 ±0.03 [c] | 1.88 ±0.03 [c] | 74.47±0.15 [de] | 25.08 ±0.02 [ab] |
| GSR10 | 7.78 ±0.07 [e] | 1.90 ±0.00 [g] | 1.12 ±0.00 [g] | 76.88±0.66 [b] | 13.86 ±3.08 [d] |
| GSR20 | 8.36 ±0.07 [c] | 2.48 ±0.01 [e] | 1.64 ±0.01 [d] | 75.75±0.66 [c] | 19.20 ±3.08 [c] |
| GSR30 | 8.95 ±0.07 [b] | 3.05 ±0.02 [b] | 2.15 ±0.02 [b] | 74.61±0.66 [de] | 24.54 ±3.08 [ab] |
| GSR40 | 9.53 ±0.07 [a] | 3.63 ±0.02 [a] | 2.67 ±0.02 [a] | 73.85±0.03 [e] | 28.10 ±0.09 [a] |

different superscripts indicate statistically significant differences ($p < 0.05$).

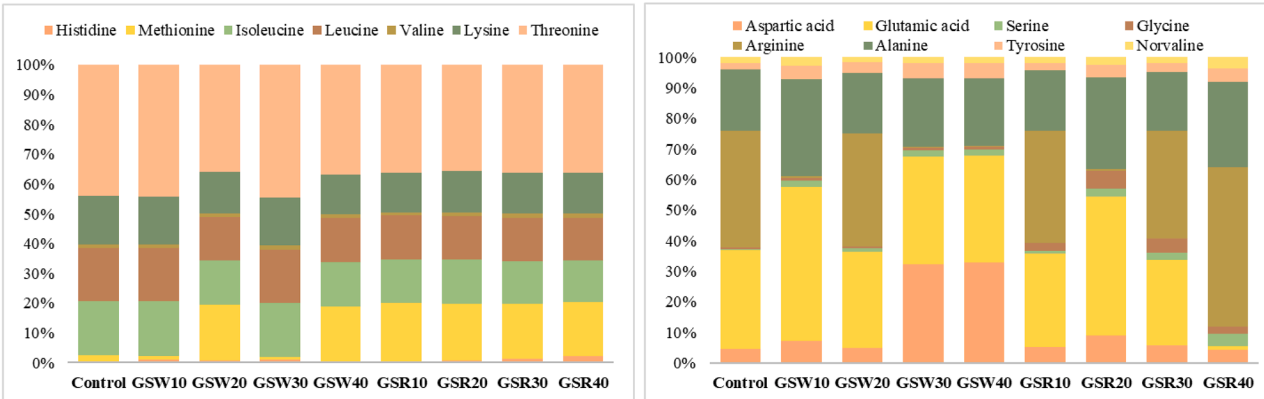


**Fig. 1.** Amino acids profile of the mixtures.

the amino acid profile of red and white grape skin by products and reported higher concentrations of glutamine, asparagine, leucine, phenylalanine and lysine in red grape skin compared to the white variety which was richer in alanine.

*3.1.2.3. Color of the mixtures.* Significant changes ($p < 0.05$) in flour mixture color parameters were observed after GSW or GSR incorporation (Table 2). L* values ranged between 87.12 for the control and 53.20 for GSR40 and decreased as the amount of grape skin was higher, with more evident changes for the GSR due to the presence of different pigments. The red nuance given by the positive values of a* ranged from 0.39 for the Control and 6.79 for GSW40.

An increasing trend, proportional to the amount of GS, was observed. On the other hand, the yellow nuance given by the b* positive values decreased from 27.38 for the Control to 5.47 for GSR40. The changes of b* were more pronounced in the red skin-containing samples compared to the white ones. Red grape pomace is rich in anthocyanin which gives the red nuance of the powder (Nascimento et al., 2018) and thus modifies the color of maize flour mixture. Other studies reported a reduction of L* and b* when grape residue or marc flour was incorporated in different products like ice cream, pasta, etc. (Nascimento et al., 2018; Sant'Anna et al., 2014). The magnitude of changes depends on the amount added and grape variety because of the presence of various pigments. White grape skin color is given by the flavonols which are yellow pigments, while in red grape skin they are masked by anthocyanins which give the orange, pink, red, blue, and purple color nuances (Ferreira et al., 2018).

### 3.2. Final product characteristics

#### 3.2.1. Expansion characteristics

The expansion characteristics of the extruded crisps are displayed in Table 3. Significant differences ($p < 0.05$) were observed between the porosity of the 2 groups of products, with the GSW samples presenting higher porosity compared to GSR and the Control. For GSW the addition level led to the increase followed by a decrease in porosity, while for GSR the unequal trend was observed. Giannini et al. (2013) reported that the addition of fiber-rich ingredients in corn extrudates resulted in lower porosity due to the presence of fibers. Bulk density raised as the amount of GS was higher for both varieties. BD is an important characteristic of the extruded crisps from a commercial point of view. These kinds of products are filled by weight and not by volume and if BD has a great variation the pack will be underfilled or overfilled (Singha and Muthukumarappan, 2018). Similar to our results, Singha & Muthukumarappan (2018) reported the increase of BD with apple pomace level increase due to the limited expansion and fiber distribution within the starch matrix of the product.

The EI decreased compared to the control and as the addition level increased. Studies reported that the supplementation of snacks with fruit pomace led to a decrease in expansion ratio and porosity depending on the dose and particle size (Wang et al., 2019; Yagci et al., 2022). For example, the study of Wang et al. (2017) revealed that the incorporation of 5 % cherry pomace powder with particle dimension <125 μm determined a greater expansion ratio compared to the other doses and the control. At low pomace levels, the amount of fiber was insufficient to fill the cell wall network, while at higher levels (>5 %) the quantity of fiber was more than what the starch matrix could sustain, resulting in a collapse of the structure which generated smaller expansion ratio (Grasso, 2020).

#### 3.2.2. Water absorption and water solubility indices

The water absorption and solubility indices are important properties of the extruded crisps which were significantly affected by the type and addition level of grape skin (Table 3). WAI values decreased as the amount of GSW or GSR was higher, and the highest value was recorded for GSW10. WAI depends on starch dispersion in excess water, and the

**Table 2**
Color properties before and after extrusion.

| Sample | Mixtures | | | Extrudates | | | |
|---|---|---|---|---|---|---|---|
| | L* | a* | b* | L* | a* | b* | BI |
| Control | 87.12±0.02 $^{a}$ | 0.39±0.08 $^{g}$ | 27.38±0.04 $^{a}$ | 78.48±0.12 $^{a}$ | 0.71±0.03 $^{f}$ | 21.75±0.20 $^{a}$ | 31.98±0.40 a |
| GSW10 | 76.77±0.09 $^{b}$ | 3.61±0.04 $^{f}$ | 21.34±0.14 $^{c}$ | 60.68±0.10 $^{b}$ | 5.75±0.05 $^{e}$ | 12.91±0.11 $^{b}$ | 30.12±0.22 b |
| GSW20 | 72.89±0.03 $^{c}$ | 5.13±0.05 $^{e}$ | 22.03±0.35 $^{b}$ | 58.98±0.27 $^{c}$ | 6.59±0.15 $^{c}$ | 12.05±0.31 $^{c}$ | 30.30±0.70 b |
| GSW30 | 70.38±0.24 $^{d}$ | 5.69±0.13 $^{d}$ | 20.89±0.39 $^{c}$ | 58.74±0.07 $^{c}$ | 6.24±0.03 $^{d}$ | 11.44±0.04 $^{d}$ | 28.73±0.08 c |
| GSW40 | 67.23±0.20 $^{f}$ | 6.79±0.01 $^{a}$ | 22.19±0.06 $^{b}$ | 54.21±0.23 $^{e}$ | 6.92±0.03 $^{a}$ | 10.86±0.07 $^{e}$ | 30.95±0.14 b |
| GSR10 | 68.24±0.22 $^{e}$ | 3.44±0.02 $^{f}$ | 11.34±0.16 $^{d}$ | 57.02±0.33 $^{d}$ | 6.64±0.07 $^{c}$ | 9.49±0.12 $^{f}$ | 26.06±0.41 d |
| GSR20 | 60.47±0.22 $^{g}$ | 5.02±0.03 $^{e}$ | 8.39±0.26 $^{e}$ | 51.84±0.31 $^{f}$ | 5.73±0.13 $^{e}$ | 6.33±0.12 $^{g}$ | 20.53±0.29 f |
| GSR30 | 56.50±0.08 $^{h}$ | 5.92±0.08 $^{c}$ | 6.29±0.18 $^{f}$ | 46.39±0.03 $^{g}$ | 6.87± 0.03 $^{ab}$ | 5.42±0.04 $^{h}$ | 22.58±0.14 e |
| GSR40 | 53.20±0.13 $^{i}$ | 6.35±0.12 $^{b}$ | 5.47±0.15 $^{g}$ | 43.08±0.21 $^{h}$ | 6.70±0.06 $^{bc}$ | 4.56±0.09 $^{i}$ | 21.87±0.22 e |

different superscripts indicate statistically significant differences ($p < 0.05$).

**Table 3**
Physical properties of the extrudates.

| Sample | Porosity* ( %) | Bulk density (g/mL) | EI | WAI* ( %) | WSI* ( %) | Cutting force (N) | Crispness (N/s) | Compression force (N) | Puncture force (N) |
|---|---|---|---|---|---|---|---|---|---|
| Control | 0.73±0.02 [bc] | 0.11±0.01[cd] | 3.70±0.03 [a] | 4.52±0.19 [c] | 31.80±0.30[b] | 14.61±1.77 [a] | 7.23±0.77 [a] | 20.09±1.46 [bc] | 10.10±1.13[b] |
| GSW10 | 0.83±0.04 [abc] | 0.11±0.01[d] | 3.32±0.16 [b] | 5.25±0.11 [a] | 33.13±0.33[a] | 7.96±0.81 [cd] | 5.82±0.59[abc] | 23.92±1.39 [b] | 10.03±0.91[bc] |
| GSW20 | 0.90±0.05 [a] | 0.10±0.00 [d] | 3.22±0.13 [b] | 4.70±0.16 [bc] | 22.71±0.27[d] | 6.03±0.61 [de] | 4.73±0.37[bcd] | 20.29±1.56 [bc] | 9.59±0.84[bc] |
| GSW30 | 0.84±0.06 [ab] | 0.15±0.00[bc] | 2.43±0.03 [e] | 4.53±0.06 [c] | 23.66±0.22[c] | 5.28±0.50 [e] | 4.43±0.54 [cd] | 16.46±1.40 [c] | 7.30±0.50 [cd] |
| GSW40 | 0.82±0.09 [abc] | 0.18±0.02[b] | 2.38±0.06 [e] | 4.06±0.02 [d] | 21.65±0.09[e] | 4.21±0.46 [e] | 3.63±0.39 [d] | 9.59±0.94 [d] | 6.38±0.63 [d] |
| GSR10 | 0.68±0.03 [c] | 0.13±0.01[cd] | 3.20±0.10 [b] | 5.07±0.25 [ab] | 11.10±0.14[h] | 8.19±0.82 [cd] | 3.82±0.27 [d] | 17.34±1.66 [c] | 11.42±1.10 [b] |
| GSR20 | 0.74±0.07 [bc] | 0.15±0.00[bc] | 2.95±0.05[c] | 5.05±0.01 [ab] | 17.92±0.17[f] | 10.50±0.67[bc] | 4.41±0.36 [cd] | 20.35±1.79 [bc] | 12.12±1.15 [b] |
| GSR30 | 0.70±0.03 [bc] | 0.23±0.03[a] | 2.80±0.0 [cd] | 4.81±0.04[abc] | 11.80±0.19 g | 11.04±1.22 [b] | 5.13±0.79[bcd] | 23.65±1.02 [b] | 15.16±1.21 [a] |
| GSR40 | 0.81±0.06 [abc] | 0.17±0.00[b] | 2.68±0.08 [d] | 4.52±0.27 [c] | 11.04±0.20[h] | 8.92±0.41 [bc] | 6.20±0.70 [ab] | 30.11±0.99 [a] | 15.44±1.03 [a] |

different superscripts indicate statistically significant differences ($p < 0.05$).
* w/w sample weight.

dispersion rises as starch damage is higher due to gelatinization and breakage caused by extrusion (Yagci et al., 2022). Our results are in agreement with those reported by Altan et al. (2008) and by Yagci et al. (2022) for extrudates fortified with tomato pomace. The reduction of WAI can be due to the competition for water between starch and fibers (Altan et al., 2008; Khajeh et al., 2025). (Różańska-Boczula et al., 2023) also reported lower WAI values of corn crisps as the percentage of dried fruit powders was higher. Smaller WAI values for crisps with GSW and GSR may be attributed to the sugars present in grape skin which may restrict gelatinization as a result of the competition for water between sugar and starch and/or sugar-starch interactions (Raleng et al., 2016). WSI of the GSW samples also decreased with the addition level increase, except for GSW30, while for GSR the changes were unequal (Table 3). Wang et al. (2017) also obtained lower WSI values for corn extrudates when cherry pomace was added since starch grains were heated, swelled, and cross-linked to capture the fibers and create the starch-fiber matrix, in addition to the starch dextrinization.

### 3.2.3. *Molecular characteristics (FTIR) of extrudates*

Compared to the control, the samples enriched with GSW or GSR presented a peak at 2850 $cm^{-1}$ due to the C—H stretching of alkyl structures (Prelac et al., 2023). Furthermore, the intensities of the absorbances increased proportionally with the addition level increase (Fig. 2). The absorption peak observed at 3310 $cm^{-1}$ is assigned to -OH stretching vibrations and can be attributed to alcohol, phenolics, and tannins (Zemni et al., 2024). The band at 2926 $cm^{-1}$ can be given by C–H stretching vibrations in the aliphatic compounds (Matei et al., 2021). The presence of flavonoids and amino acids is suggested by the

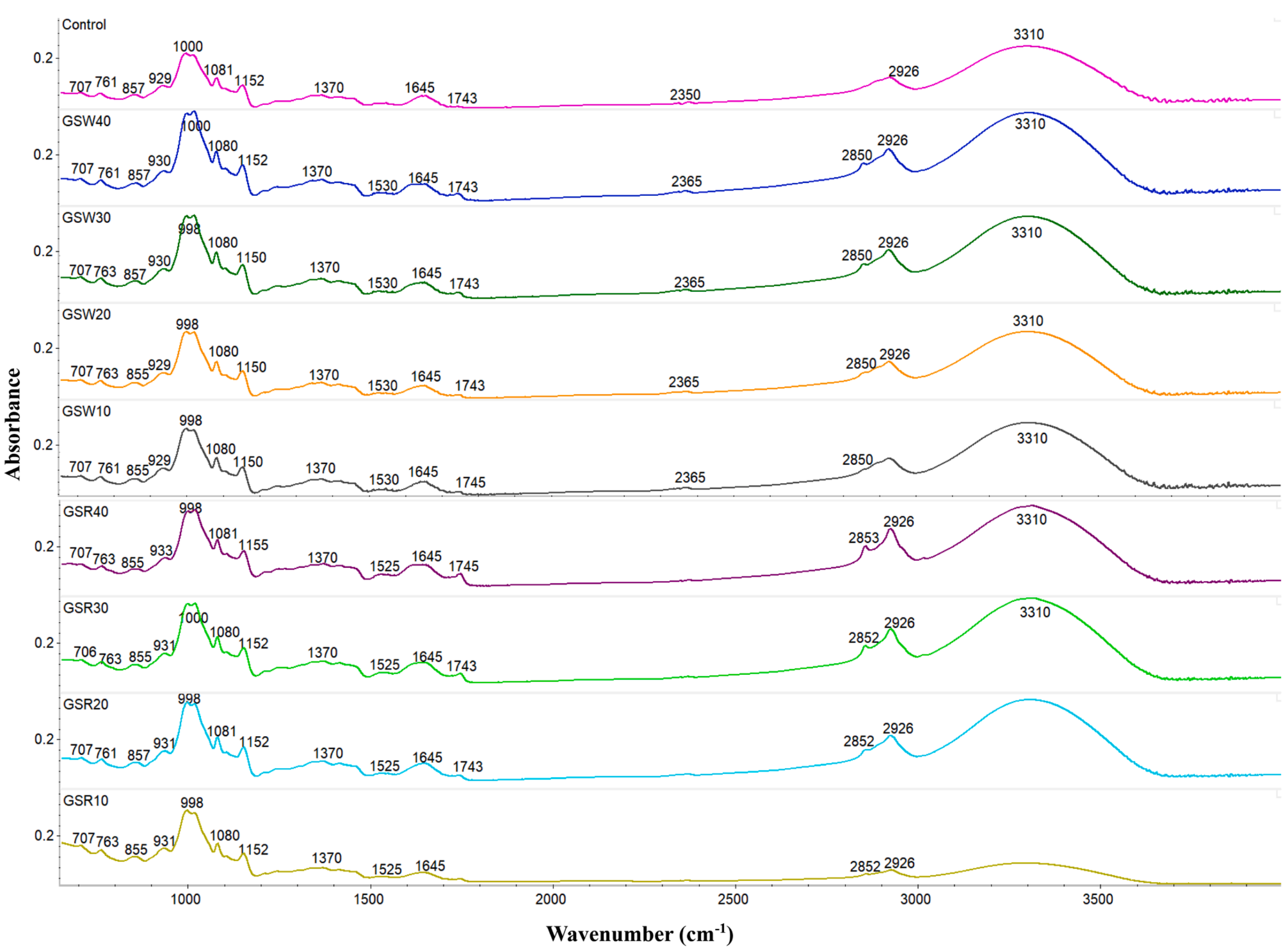


**Fig. 2.** Molecular characteristics of the extrudates.

peaks at 1743 $cm^{-1}$ due to $C = C$ groups and $C = O$ stretching vibrations (Zemni et al., 2024). The absorption band at 1645 $cm^{-1}$ can be assigned to aromatic and olefinic $C = C$ vibrations, $C = O$ amide(I), ketone, and quinone groups (Prelac et al., 2023). The CH deformation (cellulose and hemicellulose) is suggested by the peak at 1370 $cm^{-1}$ (Prelac et al., 2023), while the peak at 1000–1080 $cm^{-1}$ can be due to the contribution of C—O stretch (Fragoso et al., 2011). The peaks between 929 and 707 $cm^{-1}$ can be due to =C—H bending vibrations, while the band at 857 $cm^{-1}$ suggests the presence of C—O-C aromatic ethers which give a symmetric stretch (Prelac et al., 2023).

### *3.2.4. Starch digestion rate index*

The total starch expressed as the sum of total digestible starch and resistant starch and SDRI values are shown in Table 4. According to the results obtained, the incorporation of GSW and GSR led to an increase in total starch content, while SDRI registered small variations. The highest SDRI value was observed for GSW40. The factors affecting starch digestibility are the botanical origin, the physical state of starch, rheological properties of the food matrix, its texture, the addition of other non-starch ingredients, and the interactions that may appear among starch and these ingredients (Oladiran and Emmambux, 2018; Singh et al., 2007). The extrusion process could cause a physical breakage of the organized granular structure of maize starch and generate gelatinization and damage of starch (Román et al., 2017). This will lead to an intensification of amylolytic hydrolysis by increasing starch availability to digestive enzymes (Oladiran and Emmambux, 2018). Other studies reported that the addition of fruit pomace resulted in higher resistant starch content in pasta (Iuga and Mironeasa, 2021; Simonato et al., 2019) due to the interactions between polyphenols and starch through non-covalent bonds which can contribute to the ordered structure or expansion of starch crystallin areas and promote resistant starch formation (Chi et al., 2017; Sun and Miao, 2020). Tacer-Caba et al. (2014) also obtained an increase in resistant starch content of wheat flour extrudates when concord grape extract powder was included in the recipe.

### *3.2.5. Polyphenols*

Both GSW and GSR samples contain significant amounts of p-coumaric acid and quercetin, while the control has only p-coumaric acid (Table 4). The concentration of p-coumaric acid and quercetin increased significantly as the addition level was higher, with some exceptions. Quercetin was more abundant in GSR samples compared to GSW ones. Katalinić et al. (2010) reported higher average quercetin in red grape skin extracts compared to white ones. GSW extruded crisps exhibited significant content of rosmarinic acid which raised proportionally with the amount of grape skin. A study regarding the polyphenols content of different grape cultivars revealed that rosmarinic acid was not identified or it was in smaller amounts in red grape skin extracts (Red romy skin, Grenache noir skin), depending on the solvent used, compared to white variety (Thompson seedless skin) (El Gengaihi, 2014). GSR samples with >20 % addition level showed the presence of myricetin and luteolin which raised also as the addition level increased (Table 4). White grape varieties are rich especially in flavonols in which the B-ring is mono- and di-substituted like quercetin for example, while red grapes contain in addition tri-substituted compounds like myricetin (De Rosso et al., 2014). The study of De Rosso et al. (2014) indicated quercetin as the main phenolic compound identified in both red and white grapes cultivars. Similar to our results, Fontes-Zepeda et al. (2023) reported an increase in individual polyphenols content of corn extrudates when mango and papaya peels were added.

### *3.2.6. Color of the extrudates*

The extrusion process determined significant color changes compared to the untreated flour mixtures (Table 2): L* and b* values decreased, while a* values increased. L* and b* showed a reduction trend as the amount of GS was higher, while a* exhibited unequal changes. BI also was diminished along with the GSW and GSR incorporation, with some exceptions. The highest BI was observed for the Control (31.98). Altan et al. (2008) also reported lower L* values of snacks after tomato pomace addition. The decrease in yellowness caused by extrusion can be due to the non-enzymatic browning and pigment degradation (Altan et al., 2008; Khajeh et al., 2025). The stability of some pigments depends on various factors including extrusion temperature, pressure, time, the mechanisms and kinetics of degradation, and co-pigmentation with other polyphenols (Aĉkar et al., 2018). The study of Aĉkar et al. (2018) demonstrated that rice extrudates with carrot extract powder rich in anthocyanins exhibited a decrease of b* during extrusion. The decrease of L* with grape skin addition can be related to browning Maillard reactions and caramelization intensified by the content of sugars and proteins of grapes skins, while the changes of a* and b* parameters can be related to the pigments and heat degraded products of grape skins. A similar observation was made by Bibi et al. (2017) for corn starch extrudates with grape pomace.

### *3.2.7. Texture properties*

The texture properties of the extruded crisps showed different changes depending on the grape skin variety. For instance, GSW samples exhibited a decrease in maximum cutting force, crispness, compression force, and puncture force, while for GSR the opposite trend could be depicted. The highest cutting force and crispness were recorded for the Control. Arazo-Rusindo et al. (2025) also reported the increase of rice snacks extrudates hardness and crispness as the addition level of red grape pomace (Cabernet Sauvignon) was higher. The presence of high amounts of fiber in grape pomace can weaken the cell walls, which may produce a collapse during the expansion of air bubbles, creating thus a compact structure of the snacks (Yagci et al., 2022). The enhancement of GSR samples' crispness could be due to the soluble fibers such as pectin from red grape pomace which may exert a lubricant role within the extruder barrel, generating a crispier snack with a smaller expansion ratio (Arazo-Rusindo et al., 2025). Wójtowicz et al. (2019) studied the

**Table 4**
Starch digestion and polyphenols content of the extrudates.

| Sample | Total Starch* (%) | SDRI | p-coumaric acid (mg/kg) | Rosmarinic acid (mg/kg) | Myricetin (mg/kg) | Luteolin (mg/kg) | Quercetin (mg/kg) |
|---|---|---|---|---|---|---|---|
| Control | 35.90±0.00 f | 0.84±0.00 g | 5.25±1.21 d | 0.00±0.00 e | 0.00±0.00 d | 0.00±0.00 d | 0.00±0.00 i |
| GSW10 | 32.27±0.02 h | 0.92±0.00 b | 8.80±0.04 bc | 6.55±0.04 d | 0.00±0.00 d | 0.00±0.00 d | 21.27±0.04 h |
| GSW20 | 35.25±0.07 g | 0.85±0.00 e | 9.40±0.02 b | 14.82±0.01 c | 0.00±0.00 d | 0.00±0.00 d | 41.58±0.59 f |
| GSW30 | 41.15±0.08 c | 0.89±0.00 c | 5.93±0.46 d | 20.49±2.06 b | 0.00±0.00 d | 0.00±0.00 d | 43.56±0.00 e |
| GSW40 | 43.48±0.04 b | 0.96±0.00 a | 6.01±0.01 d | 24.93±0.03 a | 0.00±0.00 d | 0.00±0.00 d | 65.02±0.45 d |
| GSR10 | 39.79±0.09 e | 0.84±0.00 fg | 7.85±0.84 c | 0.00±0.00 e | 0.00±0.00 d | 0.00±0.00 d | 30.55±0.00 g |
| GSR20 | 40.14±0.04 d | 0.84±0.01 f | 5.91±0.02 d | 0.00±0.00 e | 54.27±0.27 c | 8.06±0.00 c | 88.94±0.45 c |
| GSR30 | 40.10±0.05 d | 0.81±0.00 h | 6.15±0.40 d | 0.00±0.00 e | 86.63±0.39 b | 18.26±0.05 b | 144.90±0.07 b |
| GSR40 | 44.66±0.10 a | 0.86±0.00 d | 14.21±0.18 a | 0.00±0.00 e | 101.63±3.22 a | 20.24±0.09 a | 181.19±1.22 a |

different superscripts indicate statistically significant differences ($p < 0.05$).
* w/w sample weight.

effects of various fruit powders (chokeberry, elderberry, and strawberry) on the properties of corn extruded snacks and revealed that firmness increased with the addition level increase, while crispness decreased, depending on the screw speed applied.

### 3.2.8. Texture sensory properties

The addition of GSW and GSR in various proportions to the maize flour resulted in changes in the sensory textural properties of the final product (Fig. 3). GSR40 samples obtained the best scores for hardness, crunchiness, and adhesiveness, while GSW10 was marked with the highest score for fracturability. The best score for chewiness was obtained by GSW40. GSR10 sample showed the lowest scores for all the characteristics considered. Asif et al. (2023) investigated the impact of citrus pomace addition on corn extrudates characteristics and observed that the scores for crispness and hardness decreased proportionally to the addition level due to the presence of fibers which affected final product expansion. Another study reported the rise of crispness values as the amount of grape pomace was higher in wheat-extruded snacks (Alshawi, 2024). The scores for corn snacks' structure (porosity and crispness) and consistency (chewiness) recorded a decreasing trend as

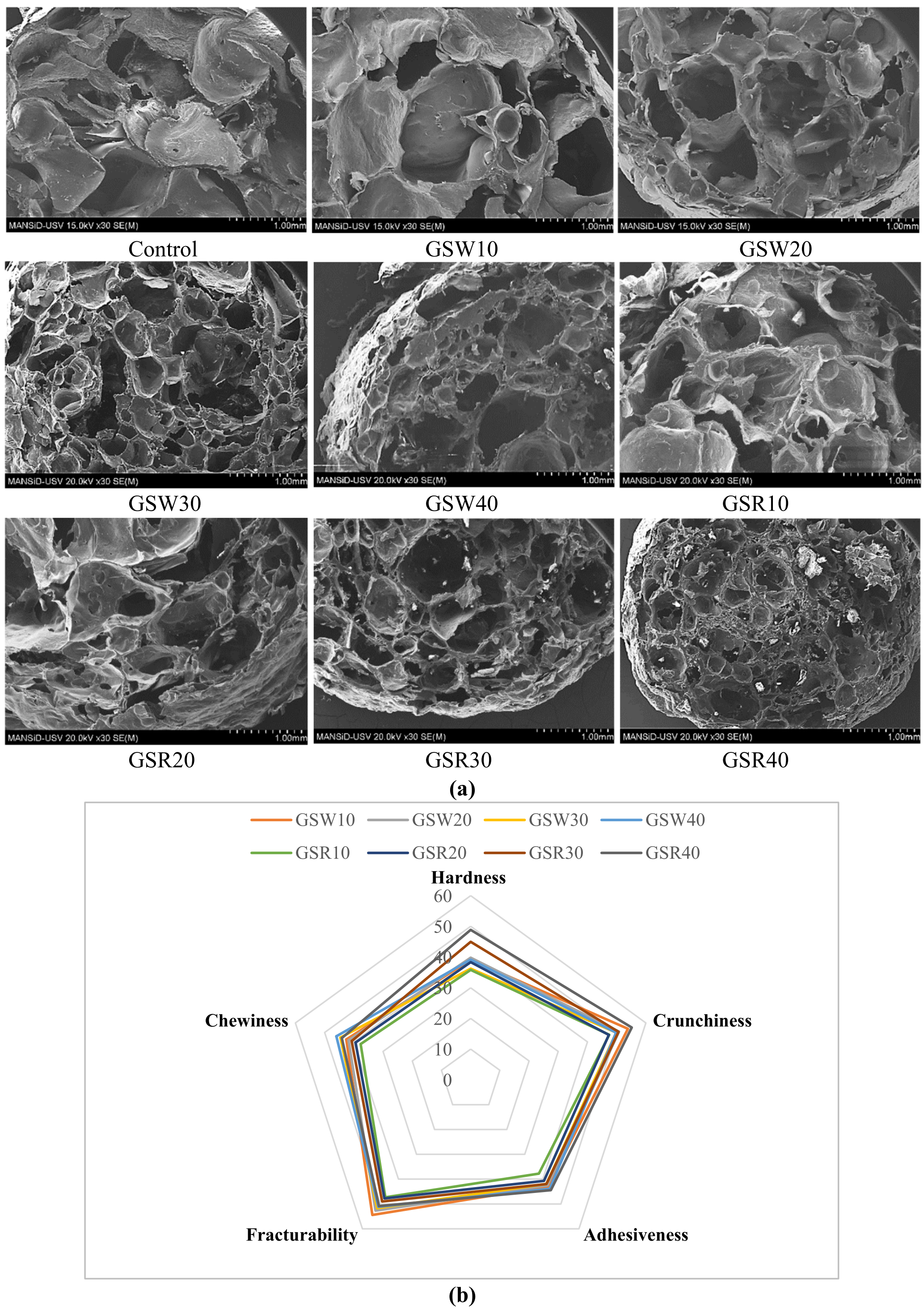


**Fig. 3.** Microstructure (a) and sensory properties (b) of the extrudates.

the amount of brewer's spent grain, sugar beet pulp, and apple pomace increased (Aĉkar et al., 2018). According to the results obtained by (Preethi et al., 2021), the best scores for crispness, chewiness, and surface characteristics of cereal-based extrudates were obtained at a 5 % addition level of cashew apple pomace, but no trendline was observed between 5–20 %. Crisps texture depends on feed mixture moisture content, and physical characteristics such as diameter, cavity space, compactness of pores, and pore wall strength (Preethi et al., 2021).

#### 3.2.9. Microstructure

The microstructure of the extruded crisps revealed a decrease in the size of the pores and an increase in their number proportional to the addition level (Fig. 3). In the samples with grape skin powder, it can be observed the entrapment of the fibrous material (grape skin) within the protein-starch matrix. The complete gelatinization of starch was observed in the extruded product.

Generally, the addition of grape skin progressively diminished the size of corn snacks and their internal cell walls became thicker and denser, which was in agreement with the results of expansion index, bulk density, and texture properties. The fiber content from grape seeds determined a compact structure with smaller values for porosity and an increased amount of small pores, which is in agreement with previous studies regarding the effects of grape pomace on rice snacks (Arazo-Rusindo et al., 2025). Grape skin exhibited a positive impact on the wall thickness since they determined thicker walls and smaller pore sizes due to a smaller expansion, corresponding to a greater bulk density. This observation is in agreement with the findings of Arazo-Rusindo et al. (2025). Singha et al. (2019) indicated some deep fissures and open space from cell wall components of the corn-soy and apple pomace extrudates along with the organized structure, which was in agreement with our results. The compact structure of the crisps with GSW and GSR can be due to the presence of fiber, proteins and/or to the starch dilution effect (Singha et al., 2019). Lotfi Shirazi et al. (2020) observed that the rise of carrot pomace quantity in barley flour mix resulted in a smaller cell size of the expanded product.

### 3.3. Relationships between variables

#### 3.3.1. Principal component analysis for the mixtures

Flour mixture Principal Component Analysis (PCA) showed that 60.94 % of data variability was explained by PC1 and 19.05 % by PC2 (Fig. 4a). The threonine, ash, fat, serine, protein, TDF, L*, lysine, alanine, threonine, leucine, isoleucine, glutamic acid, and b* variables had the major contribution to PC1, while the aspartic acid, tyrosine, arginine, and norvaline contributed more to PC2. The control and the samples with 10–20 % grape skin were clustered in the left-middle of the graphic, except GSR20, while the samples with 30–40 % grape skin were grouped in the right part. Significant strong correlations ($p < 0.05$) were obtained within the chemical compounds of the flour mixtures. The color parameters were strongly correlated ($p < 0.05$) with protein, ash, fat, carbohydrates, and TDF, except b* which was correlated significantly only with ash. The histidine, isoleucine, leucine, volume, lysine, threonine, and serine were significantly correlated ($p < 0.05$) with protein, fat, and ash content. The carbohydrates and TDF content were also correlated ($p < 0.05$) with some of the amino acids (isoleucine leucine, threonine, and serine). L* and b* parameters were strongly correlated ($p < 0.05$) with isoleucine, leucine, valine, threonine, and serine, while a* was correlated only with serine and tyrosine.

#### 3.3.2. Principal component analysis for the extrudates

The relationships between the characteristics of the extruded crisps are displayed in Fig. 4b From the total data variability, 44.99 % was explained by PC1 and 24.59 % by PC2. The major contribution to PC1 was attributed to b*, WSI, BI, bulk density, rosmarinic acid, puncture force, compression force, myricetin, luteolin, quercetin, hardness, and total starch. The WAI, EI, crunchiness, adhesiveness, and chewiness contributed to a larger extent to PC2. The samples with white skin were grouped in the left quadrants, while the ones with red grape skin were positioned in the right quadrants, except GSR10. The total starch was negatively correlated with EI ($p < 0.05$). L*, b*, and BI color parameters were significantly correlated ($p < 0.05$) with some of the polyphenols (myricetin, luteolin, quercetin). Significant correlations ($p < 0.05$) were observed between bulk density and luteolin, myricetin, and quercetin content respectively, while WAI was correlated with chewiness. Puncture force and hardness were correlated ($p < 0.05$) with myricetin, luteolin, and quercetin. A significant positive correlation ($p < 0.05$) was observed between crispness and hardness and crunchiness.

## 4. Conclusion

Grape skin by product properties are influenced by variety. This ingredient can enhance the nutritional value of maize-extruded crisps

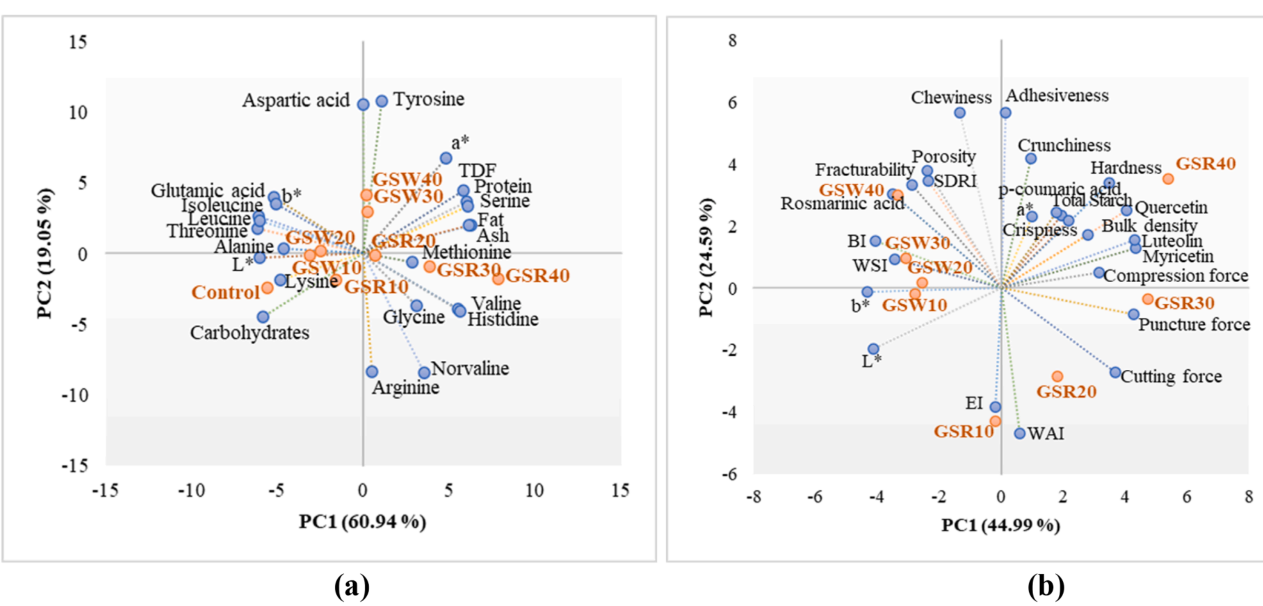


**Fig. 4.** Principal component analysis for the mixtures (a) and extrudates (b).

due to its high content of dietary fiber and polyphenols. Grape skin incorporation in maize flour resulted in increased nutrients content, including protein, fat, ash, dietary fiber, and some amino acids of the mixtures, while the color properties differed depending on the grape variety (red or white). Extruded crisps quality was influenced by the addition level and type of grape skin. A decrease in expansion index, water absorption, and solubility was obtained as the amount of grape skin was higher. Samples with white grape skin exhibited a reduction of texture parameters, while for the red ones they raised. The absorbances of the FT-IR spectra peaks were higher as the quantity of grape skin increased. The content of total starch, quercetin, and p-coumaric acid increased proportionally with the addition level and compared to the control. The best scores for hardness, crunchiness, and adhesiveness were obtained by the sample with 40 % red grape skin. Pores dimension decreased and their number increased as the amount of grape skin increased in the extruded snacks. In-depth studies of the interactions between grape skin by products and the components of maize flour are needed in the future.

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## Human and animal rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans as well as in accordance with the EU Directive 2010/63/EU for animal experiments.

## Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s) and/or volunteers.

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## Author statement

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

## CRediT authorship contribution statement

**Silvia Mironeasa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mădălina Ungureanu-Iuga:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Costel Mironeasa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mircea-Adrian Oroian:** Writing – review & editing, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gelu-Marius Rotaru:** Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation.

## Declaration of competing interest

The results were first used in a patent application entitled "Process for obtaining an extruded non-gluten product, direct-expanded and product so obtained" ("Procedeu de obţinere a unui produs aglutenic extrudat, direct-expandat şi produs astfel obţinut").

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2025.100727.

## Data availability

Data will be made available on request.

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