Seedless grape pomace to increase fiber content in extruded corn snacks

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Abstract

Introduction. Extruded snack nutritional value can be enhanced by incorporating functional ingredients like seedless grape pomace – a winery's valuable by-product that is usually discarded.

Materials and methods. This work aimed to evaluate the impact of seedless grape pomace from two varieties (red and white) on extruded corn snack quality: expansion characteristics, starch digestibility, color, texture, and functional properties. The best formulation was evaluated by the nutritional profile, antioxidant activity, and polyphenol content.

Results and discussion. Grape variety affected the content of total starch, snacks porosity, starch digestion index, lightness, browning index, cutting, compression and puncture forces, chewiness, and functional properties of extruded snacks added with grape pomace. Increasing the amount of grape pomace in snacks resulted in a decrease in expansion index, water absorption and solubility indices, total starch content, lightness, friability, cutting, compression and piercing forces, and crispness, while chewiness, browning index, and starch digestibility index increased when as the addition level of the plant additive was higher. The recommended addition levels were 30% for white seedless grape pomace and 20% for the red one. The characterization of these two samples in comparison with the control demonstrated that if even the porosity, texture parameters, lightness, and functional properties were lower, the general quality of the final product was acceptable. The fortified samples had a higher content of protein, ash, lipids, and fiber, and they demonstrated significantly higher antioxidant activity compared to the control. The fiber content was more than 23 fold higher in the the white seedless pomace-containing sample and more than 37 fold in the red one compared to the control corn snack. Furthermore, some individual polyphenols like quercetin, luteolin, and myricetin were identified only in the fortified snacks, depending on grape variety. The FT-IR spectra registered higher absorbances for the fortified snacks than those of control.

Conclusion. The results confirmed the opportunity to valorize seedless grape pomace in the extrusion process to obtain functional snacks with potential health benefits.

Introduction

World grape production was estimated at 73.5 million tons in 2021 (Statista, 2023), and most of the grapes (around 75%) are used for winemaking (Stabnikova et al., 2023), which generates a large amount of by-products (seeds, skins, and stem residues) called grape pomace, most of which is not used and pose environmental problems (Andrade et al., 2019; Dwyer et al., 2014). Annual global production of grape pomace consists from 10.5 to 13.1 million tons (Gómez-Brandón et al., 2019; Oliveira et al., 2024). Meanwhile, grape pomace contains valuable compounds, and recently much research has been carried out on its use in the production of functional foods (Almanza-Oliveros et al., 2024; Baroi et al., 2022; Grevtseva et al., 2023; Stabnikova et al., 2021; Troilo et al., 2022).

Therefore, it is of crucial importance to reuse these by-products to enhance process economics and its sustainability. The strategy of recycling grape winemaking by-products involves reusing them as raw material for a subsequent process, such as extrusion, to produce higher value products. The incorporation of grape by-products in extruded snacks includes in addition to health benefits by creating value-added snacks with high nutritional profile, and, environmentally sustainable benefits.

Seedless grape pomace is well-known as good source of fibers (65–80%) (Llobera and Cañellas, 2008; Valiente et al., 1995), polysaccharides (Beres et al., 2017; Bordiga et al., 2019) containing also multiple types of polyphenols, such as anthocyanins, hydroxycinnamic acids, catechins, and flavonols (Kammerer et al., 2004). These polyphenols have been affirmed to have antioxidant properties (Deng et al., 2011; Ivanov et al., 2021) and inhibit low-density lipoprotein oxidation (Yıldırım et al., 2005). Additionally, dietary fiber is recognized as a beneficial component of a healthy diet, with benefits including lowering cholesterol and blood sugar levels, improving cardiovascular health, and preventing constipation and obesity (Deng et al., 2011; Sagar et al., 2018; Stabnikova and Paredes-Lopez, 2024). The phytochemicals content of seedless grape pomace is known to vary depending on the type of grape (red or white), grape cultivar, growth climates, and processing conditions. Deng et al. (2011) reported that total dietary fiber was the predominant composition in the red wine grape pomace but not in the white wine grape pomace in which soluble sugar was in the largest amount. The seedless grape pomace from the red variety are usually rich in anthocyanidins that are neglected in white varieties (Yu and Ahmedna, 2013).

Extrusion technology, one of process with high productivity and versatility, offers the possibility to incorporate different types of by-products in snacks to develop new products or to improve nutritionally the products that are carbohydrate-rich or glycemic-high (Paraman et al., 2015). Corn grits, the major ingredient used for the production of extruded snacks, contains a high amount of starch and less nutrients, and it's improvement with other raw materials has been approached in various studies. An increase of fiber level in extruded snacks would offer a nutritional benefit, and the seedless grape pomace shows the appropriate characteristics (Deng et al., 2011) since it contains a great quantity of hemicellulosic sugars (Bordiga et al., 2019). However, it is a food engineering challenge to design palatable extruded foods having high content of dietary fiber due to the low expansion capability of polymer matrices that contain large amounts of dietary fiber (Sozer and Poutanen, 2013). Expansion rates at high fiber content can be enhanced when there are present soluble non-digestible oligo- and polysaccharides. Grape skin cell walls are considered an important source of polysaccharides, with the content of soluble polysaccharides varying depending on the grape variety (Zhai et al., 2024). The oligosaccharides represent the natural by-products of the degradation of berry cell wall polysaccharides (Bordiga et al., 2019). These components will not only improve expansion rates but also provides additional functional properties, acting as nutrients for the colonic microflora of humans (Bordiga et al., 2019; Sozer and Poutanen, 2013). The polysaccharide-lipid complexes formed during the extrusion process contribute to the insoluble fiber fraction, together with resistant starches formed under harsh extrusion conditions (Gualberto et al., 1997). Increasing the content of insoluble dietary fiber and reducing starch digestibility in nutritious snacks is desirable, but their acceptability by consumers from sensory and textural properties points of view must also be taken into account.

The possibility of using seedless grape pomace in high proportion in corn snack production with satisfactory physical, functional and textural properties, acceptable or desired for consumers has not investigated yet. The incorporation of by-products with a higher content of dietary fiber is known to cause lower expansion during extrusion, resulting products with unacceptable features (Stojceska et al., 2010). Until now, the investigations reported the valorization of grape by-products in extruded snacks at levels up to 20%. There is not known research about the application of seedless grape pomace above this limit in the production of expanded products based on corn flour so far.

The results of the present study could reveal the level of this ingredient, which can be added to corn flour to enhance the nutritional profile of snacks. The main aim of this research was to investigate the possibility of using seedless grape pomace from white and red grape varieties in considerable amounts in the production of corn snacks, and to estimate the best percentage that can be added in corn flour to obtain snacks with desired characteristics.

Materials and methods

Materials

The red and white grape pomaces were provided by the Iaşi Research and Development Center for Viticulture and Vinification, while the corn was purchased from a local Romanian producer. After drying the pomace in a convection oven (ZRD-A5055, Zhicheng Analysis Instrument, Shanghai, China) at 50°C until its moisture content became below 10%, the seeds were manually separated, and the remaining grape skins were ground using a laboratory mill (Perten 3100, Perten Instruments, Huddinge, Sweden). The ground grape skin was then sieved through a mesh smaller than 0.2 mm to obtain a uniform powder. Flour mixtures were created by blending corn flour with either white (SGPW) or red (SGPR) grape skin in varying proportions (10–40%), with the corn flour serving as the control.

Extrusion parameters

A laboratory single-screw extruder (Kompakt extruder KE 19/25, Brabender, Duisburg, Germany) was used. The extruder had a barrel diameter of 19 mm and a length-to-diameter ratio of 25:1, equipped with a 2 mm diameter nozzle. The feeding rate was maintained at 24 rpm, and the screw speed was set to 150 rpm. The temperature settings for the four processing stages were 50°C, 95°C, 175°C, and 180°C. After extrusion, the products were cooled to room temperature and left to equilibrate for 16 hours before storage.

Methods

Expansion characteristics

As extrusion leads to an expanded product, the expansion index (EI) was determined. EI was calculated by measuring 20 segments from each sample using a digital caliper. To determine porosity, 15 product pieces were placed in a 250 mL cylinder filled with mustard seeds. The volume of mustard seeds without the snacks was also recorded, with the difference indicating the bulk volume. The same snacks were then ground into a fine powder, and the resulting volume was measured in the same cylinder, representing the apparent volume. The difference between the bulk and apparent volumes provided an estimate of the internal void volume, allowing the material's porosity to be assessed (Rathod and Annapure, 2017).

Digestibility of starch

Total starch content was measured using a Megazyme kit (K-DSTRS; Megazyme, Bray, Ireland) following the manufacturer's instructions (Batariuc et al., 2023). Total digestible starch was determined using a spectrophotometric method, and the starch digestion index (SDRI) was calculated as the ratio of rapidly digestible starch (after 20 min of digestion) to total starch.

Color

The ground snacks were placed in transparent petri dishes, and the surface was leveled. The color parameters—Lightness (L*), green to red hue (a*), and yellow to blue hue (b*) were measured using a CR-400 device (Konica Minolta, Tokyo, Japan). The browning index (BI) was then calculated based on methods described in the literature (Al-Hilphy et al., 2022).

Texture

The texture of the snacks was analyzed using a TVT 6700 texturometer (Perten Instruments, Hägersten, Sweden). A single-cycle compression test was conducted on 1 cm-long samples, applying a compression of 50% at a test speed of 1 mm/s with a 25 mm cylindrical probe. The cutting force was measured using a V-shaped cutting blade, perpendicular to 4 cm-long samples, also at a test speed of 1 mm/s. Crispness was assessed by analyzing the slope of the first peak during the test. Additionally, a puncture test was performed on 1 cm-long samples using a 3 mm diameter puncture probe, at the same speed of 1 mm/s.

Sensory analysis

The crunchiness and chewiness of the snacks were evaluated by 65 panelists from the Food Engineering Faculty at Stefan cel Mare University of Suceava. Each panelist was instructed to consume and swallow coded samples of the extruded snacks, rating the intensity of each attribute on a nine-point scale, following the guidelines of ISO 8589:2007. Mineral water was provided for mouth cleansing between tastings.

Functional properties

The water absorption index (WAI) was determined as outlined by Ratod and Annapure (Rathod and Annapure, 2017). A sample of 2.5 g of ground extrudates was suspended in 25 mL of water at room temperature for 30 min with intermittent stirring, followed by centrifugation at 3000 rpm for 15 min. After removing the supernatant, the hydrated residue was weighed. The supernatant was poured into a pre-weighed evaporating dish, and the water was evaporated to a constant weight to determine the dry solids. The water absorption index (WAI) was calculated as the weight of the hydrated residue per unit weight of the original dry solids. The water solubility index (WSI) was calculated as the weight of dry solids in the supernatant, expressed as a percentage of the original sample weight.

Polyphenols quantification

For the separation and quantification of individual phenolics, phenolic extracts were analyzed using a High-Performance Liquid Chromatography (HPLC) system (Shimadzu, Kyoto, Japan), which included a LC-20 AD liquid chromatograph, SIL-20A autosampler, CTO-20AC column oven, and SPD-M-20A diode array detector. Separation was performed on a Phenomenex Kinetex® 2.6 µm Biphenyl 100 Å HPLC column (150 × 4.6 mm) thermostated at 25°C. The injection volume was set at 10 µL, with solvents consisting of 0.1% acetic acid in water (solvent A) and acetonitrile (solvent B). The gradient started with 100% A, transitioning to 5% B at 6.66 min, 40% B at 66.6 min, and 80% B at 74 min. The solvent flow rate was maintained at 1 mL/min. Polyphenols were identified by comparing retention times with those of standard solutions, and quantification was based on absorbance in the chromatograms, measured relative to external standards at 320 nm for p-coumaric acid, rosmarinic acid, myricetin, luteolin, and quercetin. The standard calibration curves had regression coefficients of $R^2 > 0.99$.

FT-IR spectra acquisition

The molecular characteristics of the extruded products were analyzed using Fourier Transform Infrared (FTIR) spectroscopy with a Thermo Scientific Nicolet iS20 spectrophotometer (Waltham, MA, USA) equipped with an attenuated total reflection (ATR) accessory. Spectra were collected in the range of 650 to 4000 cm^{-1}, with a resolution of 4 cm^{-1} and 32 scans. The molecular features were identified based on established literature (Nogales-Bueno et al., 2017; Reinaldo et al., 2021) and analyzed using OMNIC software (version 9.9.549, Thermo Fisher Scientific, Waltham, MA, USA).

Nutritional profile

The nutrients composition (moisture, lipids, protein, and ash) of the snacks was determined by following the ICC standard instructions: moisture (101/1), fat (104/1), protein (105/2), and ash (105/1). The total dietary fiber was evaluated with a Megazyme kit (K-TDFR-200a 04/17) following the AACC 32-05.01 method.

For DPPH antiradical activity (AA DPPH), samples were extracted via ultrasonication by mixing 1 g of the sample with 10 mL of acetone: water acid solution (70:28:2) at 45°C for 1 hour. Cold water was added to the bath every 15 min to maintain the temperature. A 0.5 mL portion of the extract was mixed with 0.5 mL of 80% methanol and 5 mL of DPPH solution, then incubated for 30 min in the dark at room temperature. Absorbance was recorded at 517 nm using the same spectrophotometer.

Statistical analysis

The single and combined impact of grape pomace variety (red or white) and addition level (10, 20, 30, or 40%) on snacks quality in terms of porosity, expansion index, total starch, starch digestion index, L*, BI, cutting force, crispness, compression force, puncture force, crunchiness, chewiness, water absorption index, and the water solubility index were evaluated by using quadratic, cubic or 2FI models. Models fitting was checked by Analysis of Variance (ANOVA) at a significance level of $p < 0.05$ and by considering the F-value, p-value, R^2 and $Adj.\text{-}R^2$. The differences among samples were evaluated by using Tukey test ($p < 0.05$). The statistical modelation of data was performed by using XL STAT 2024 version and Stat Ease Design-Expert (trial version).

Results and discussion

The impact of seedless grape pomace variety and its addition level on corn snack quality was evaluated by applying different mathematical models (Table 1).

Porosity was affected significantly ($p < 0.05$) by grape variety, while the expansion index was influenced by the addition level and the interaction between grape variety and addition level. A slight increase of porosity with the addition level rise was observed (Figure 1).

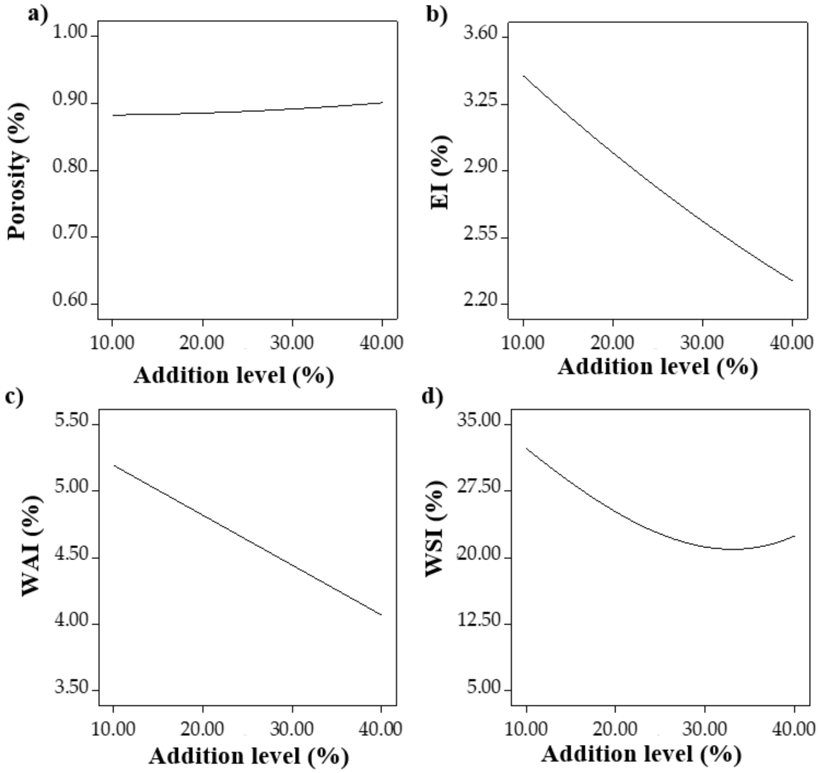

Figure 1. Dependence of porosity (a), expansion index (EI) (b), water absorption index (WAI) (c), and water solubility index (WSI) (d) on addition level of seedless grape pomace

On the other hand, higher amounts of seedless grape pomace caused the decrease of the expansion index. Similar, a reduction of the expansion index was reported by Soja et al. (2024) for snacks from potato starch and different plant pomaces due to the high amount of fiber present in the plant ingredient which led to lower expansion capacity. Another study reported that the incorporation of chokeberry and cherry pomaces in corn extruded snacks resulted in a lower expansion rate (Gumul et al., 2023). The results obtained in our study regarding the decrease of snacks porosity and expansion could be due to the simultaneous effect of fiber and polyphenols from seedless grape pomace which affected the final product texture (Soja et al., 2024). The expansion of snacks depends on the starch content of the flour because it presents viscoelastic characteristics. The bubbles generated during heating by the water evaporation enter into the swelling starch grains and determine their expansion (Karkle et al., 2012). Thus, replacing corn flour with seedless grape pomace rich in fiber generated a starch dilution effect and decreased the expansion.

Table 1

ANOVA results for mathematical models fitted for properties evaluated

Factor	Porosity (%)	EI (%)	Total starch (%)	SDRI	L*	BI	Cutting force (N)	Crispness (N/s)	Compression force (N)	Puncture force (N)	Crunchiness	Chewiness	WAI (%)	WSI (%)
Intercept	0.81	2.84	39.05	0.84	54.02	26.39	8.33	4.77	20.18	11.07	49.43	41.54	4.75	18.99
A-Variety	-0.08**	0.04	1.57**	-0.03**	-5.02**	-3.63**	1.89**	0.12	2.65**	2.60**	-0.73	-1.53**	0.11**	-3.66**
B-Level	0.03*	-0.40**	4.06**	0.02**	-4.17**	-0.72	-0.70*	0.08	-0.39	0.14	1.83	3.20*	-0.42**	-4.01
AB	0.02	0.14**	-1.87**	-0.01	-2.07**	-0.86*	1.10**	1.11**	6.63**	2.12**	2.96**	0.58	0.13**	2.04**
B^2	0.01	0.05	1.00	0.06**	-0.27		-1.01*		0.07	-0.26	2.15*	1.04		0.23
AB^2					1.32**						0.47	-0.17		-4.50**
B^3					-0.94						-0.91	-0.74		1.12
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
R^2	0.80	0.85	0.95	0.88	0.99	0.89	0.85	0.77	0.94	0.92	0.81	0.84	0.86	0.94
$Adj.\text{-}R^2$	0.76	0.81	0.93	0.85	0.99	0.87	0.82	0.73	0.93	0.90	0.75	0.89	0.84	0.91

* - significant at $p < 0.05$, ** - significant at $p < 0.01$

EI - expansion index; SDRI - starch digestion index; WAI - water absorption index; WSI - water solubility index

Snacks' functional properties were influenced by grape variety and its interaction with the addition level ($p < 0.05$), while the latest had a significant impact only on the water solubility index. Both the water absorption index and water solubility index showed a decreasing trend proportional with the addition level increase (Figure 1).

The water absorption index is a measure of the distribution of starch in excess water and is dependent on starch damage and the reduction in amylose and amylopectin mass during processing (Yağci and Göğüş, 2008). It depends on the number of hydrophilic groups and on the ability of starch to form a gel structure (Raleng et al., 2016). The great sugar content of grape pomace could have been reduced starch gelatinization due to the competition for water of these two types of molecules and/or could have been determined the formation of complexes between them (Lund, 1984). Similar results were reported by Raleng et al. (2016) for rice-pigeon pea snacks with pineapple pomace. The quantity of soluble polysaccharides released from starch during thermal processing through dextrinization can be estimated by the water solubility index (Ding et al., 2005). Poliszko et al. (2019) studied the impact of pumpkin flour on corn snacks properties and also reported a decrease of the water solubility index.

Total starch and starch digestion index (SDRI) were influenced by both grape variety and addition level ($p < 0.05$), but only total starch was affected by their interaction. Total starch content increased with the addition level increase, while the starch digestion index first decreased, then it raised at levels > 30% (Figure 2).

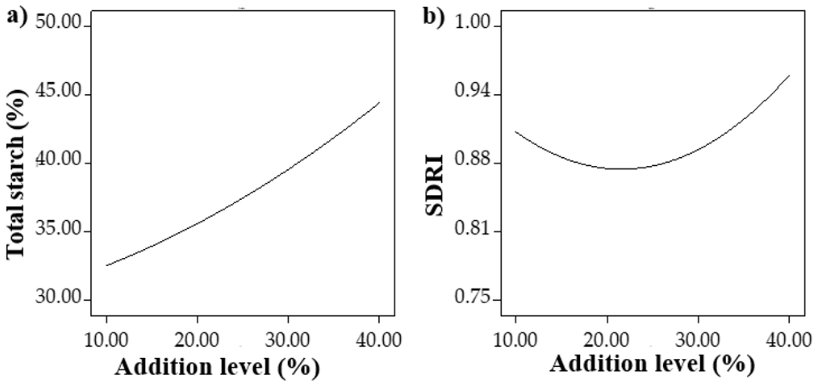

Figure 2. Dependence of total starch (a) and starch digestion index (SDRI) (b) on addition level of seedless grape pomace

The increase in starch digestibility could be due to a weaker snacks microstructure, and a greater contact surface determined by the presence of grape pomace (Raleng et al., 2022). Grape variety, the addition level, and their interaction had a significant effect ($p < 0.05$) on snacks lightness (L*). On the other hand, the browning index (BI) was influenced by grape variety and its interaction with the addition level. A reduction of L* values was observed as the addition level raised, while the browning index recorded slight changes (Figure 3).

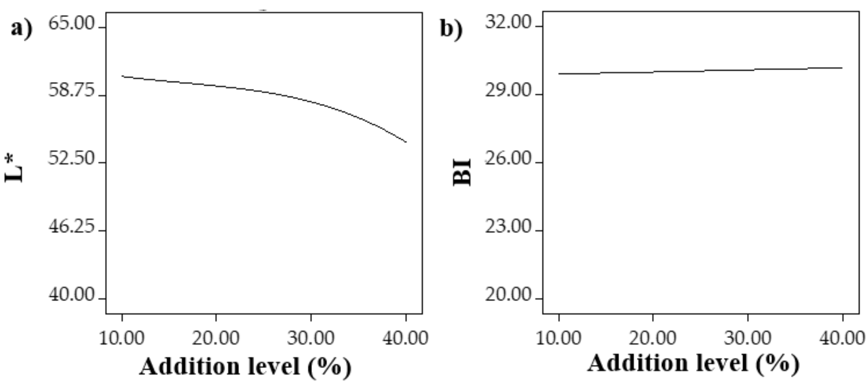

Figure 3. Dependence of L* (a) and browning index (BI) (b) color properties on addition level of seedless grape pomace

Altan et al. (2008) also reported a decrease of barley snacks L* values when tomato pomace was added. Non-enzymatic browning reactions and pigments degradation could be responsible for color changes during extrusion (Altan et al., 2008). The increase in pomace quantity led to the intensification of these modifications which may explain the reduction of L* and the increase of browning index.

All texture parameters (cutting force, crispness, compression force, and puncture force) were influenced by the interaction between grape variety and addition level, while the single effect of variety was significant ($p < 0.05$) only on cutting force, compression force, and puncture force. Only the cutting force was affected by the addition level ($p < 0.05$). All the texture properties (cutting force, crispness, compression force, and puncture force) decreased proportionally with the addition level increase (Figure 4). The decrease of these texture parameters could be possibly explained by the presence of pectin from grape peels, which may act as a lubricant and decrease snacks hardness (Singha et al., 2019). Similar trends for cutting force and hardness of corn snacks with dried fruits were reported by Różańska-Boczula et al. (2023). These results could be due also to the damage on the internal structure and the reduction of matrix cohesion because of high fiber and non-starch components content induced by grape pomace, which may lead to starch gelatinization disturbance.

Crunchiness was siginicanlty affected by the interaction of grape variety and addition level ($p < 0.05$). Chewiness was affected by both grape variety and addition level, with a greater impact of the grape type. The addition level increase caused a reduction of crunchiness and an increase of snacks chewiness (Figure 5). Różańska-Boczula et al. (2023) reported lower crispness as the amount of elderberry powder was higher in corn-based snacks. At low addition levels snacks structure encompasses bigger air bubbles that make them being more delicate. On the other hand, at higher grape pomace levels, the air pores are smaller and the structure is more rigid, leading to a less crunchy snack. The higher fiber content of grape pomace caused a denser structure, which resulted in higher chewiness, similar with the findings obtained by Dangal (2023).

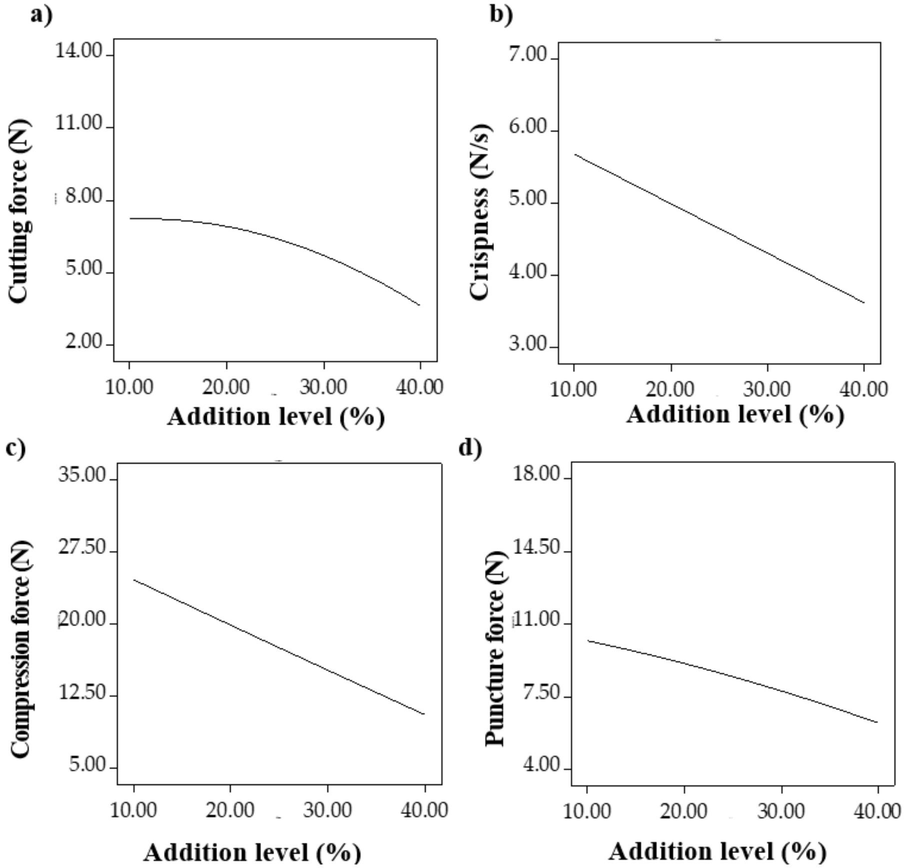

Figure 4. Dependence of cutting force (a), crispness (b), compression force (c), and puncture force (d) on addition level of seedless grape pomace

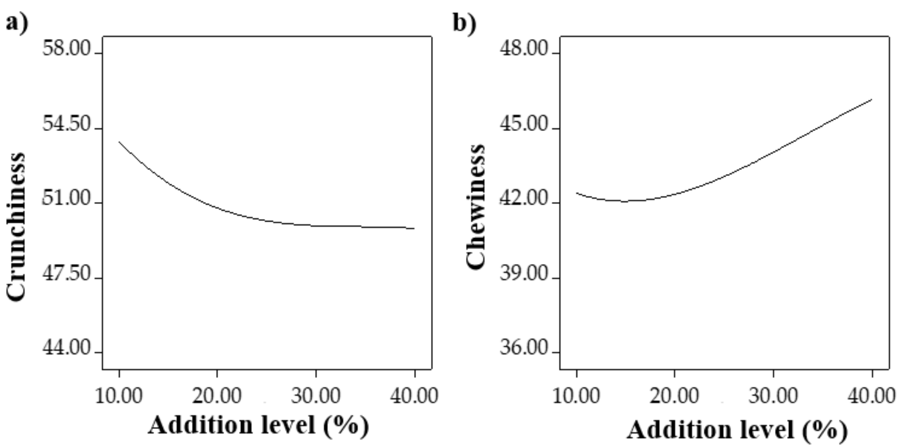

Figure 5. Dependence of crunchiness (a) and chewiness (b) texture properties on addition level of seedless grape pomace

To select the best formulations, the maximum porosity, EI, and chewiness, and the minimum cutting force, compression force, puncture force, and water absorption index were considered. Thus, an addition level of 30% for white seedless grape pomace (SGPWO) and 20% for the red seedless grape pomace (SGPRO) were recommended and further characterization of them was performed.

The highest porosity was observed for white seedless grape pomace, while the EI was better in the case of control sample (Table 2). This may be due to the high fiber content of the grape pomace incorporated. Both fortified samples exhibited higher total starch content compared to the control, while the greatest starch digestion index (SDRI) was found for white seedless grape pomace. These changes could be related to the structure density of the fortified snacks (Raleng et al., 2022). Both grape pomace types caused significant changes of L* and browning index by lowering the values obtained, which can be explained by the presence of pigments and/or the intensification of Maillard reactions due to the chemical composition of the ingredients added (Lohinova and Petrusha, 2023; Yu et al., 2018). Control sample exhibited greater cutting force, crispness and compression force compared to both fortified snacks. Red seedless grape pomace presented the highest puncture force. This may be explained by the more compact structure of the control and by the dilution effect of grape pomace fiber, which was different depending on the chemical composition of each grape variety (Różańska-Boczula et al., 2023). The white seedless grape pomace sample was more chewable compared to the red seedless grape pomace, while the crunchiness did not differ among them. The highest water absorption index was obtained for red seedless grape pomace, while the water solubility index of both fortified samples was lower compared to the control. A reduced water solubility index is desired from a nutritional perspective because it induces a lower digestion and intestinal absorption (Poliszko et al., 2019).

Table 2

Fortified samples properties compared with control sample

Indicators	**SGPWO**		**SGPRO**		**C**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Level (%)	30	-	20	-	0	-
Porosity (%)	0.89^{a}	0.05	0.71^{b}	0.05	0.73^{b}	0.02
EI (%)	2.61^{c}	0.15	2.95^{b}	0.15	3.70^{a}	0.03
Total starch (%)	39.93^{a}	1.00	40.09^{a}	1.00	35.90^{b}	0.00
SDRI	0.89^{a}	0.02	0.81^{b}	0.02	0.84^{b}	0.00
L*	57.12^{b}	0.88	51.69^{c}	0.88	78.48^{a}	0.12
BI	30.08^{a}	1.46	23.20^{b}	1.46	31.98^{a}	0.40
Cutting force (N)	5.58^{c}	1.01	10.03^{b}	1.01	14.61^{a}	1.77
Crispness (N/s)	4.25^{b}	0.50	4.56^{b}	0.50	7.23^{a}	0.77
Compression force (N)	14.82^{b}	1.62	21.10^{a}	1.62	20.09^{a}	1.46
Puncture force (N)	7.56^{b}	1.01	12.90^{a}	1.01	10.10^{b}	1.13
Crunchiness	49.47^{a}	1.43	48.02^{a}	1.43	-	-
Chewiness	44.49^{a}	1.33	39.63^{b}	1.33	-	-
WAI (%)	4.41^{b}	0.16	4.94^{a}	0.16	4.52^{b}	0.19
WSI (%)	23.24^{b}	3.06	13.12^{c}	3.06	31.80^{a}	0.30

Mean values followed by different letters in the same row are significantly different ($p < 0.05$)

WAI - water absorption index; **WSI** - water solubility index; **SDRI** - starch digestion index; **BI** - browning index; **SGPWO** - white seedless grape pomace; **SGPRO** - red seedless grape pomace.

Characterization of the best samples

The appearance of the samples selected is shown in Figure 6.

C SGPWO SGPRO

Figure 6. Extruded corn snacks with white seedless grape pomace (SGPWO) and red seedless grape pomace (SGPRO) *vs.* control (C)

The content of polyphenols identified in the fortified and control snacks is presented in Figure 7. p-coumaric acid was present in all the analysed samples and showed very close values. Quercetin was found in both fortified snacks, with the red one (SGPRO) exhibiting the highest concentration. SGPWO contains rosmarinic acid, which was not found in the other sample. On the other hand, SGPRO contains significant amounts of luteolin and myricetin, which were not present in the other snacks. The results are in agreement with previous studies which reported higher content of myricetin and quercetin in red grapes compared to white varieties (Gomes et al., 2019), while rosmarinic acid is found in higher amounts in white grapes (Squillaci et al., 2021).

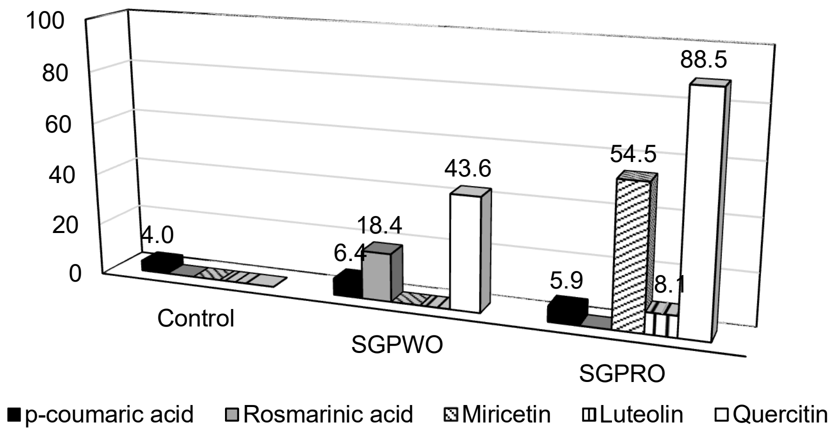

Figure 7. Polyphenols content of extruded corn snacks with white seedless grape pomace (SGPWO) and red seedless grape pomace (SGPRO) *vs.* control (C)

The addition of seedless grape pomace resulted in an increase of FT-IR peaks intensities compared to the control (Figure 8). More pronounced peaks at 2374 and 1745 cm^{-1} were observed for the fortified samples compared to the control.

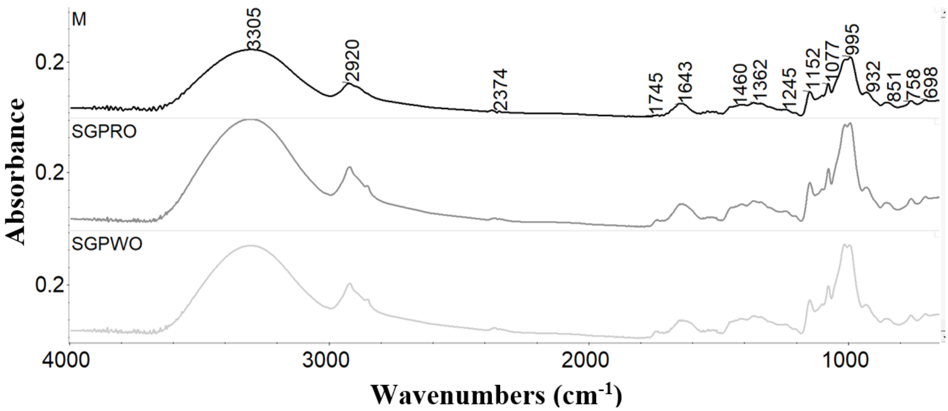

Figure 8. FT-IR spectra for extruded corn snacks with white seedless grape pomace (SGPWO) and red seedless grape pomace (SGPRO) *vs.* control (C)

The peak at 3305 cm^{-1} corresponds to the -OH stretching vibration, while the peaks at 2920 cm^{-1} correspond to the C-H stretching vibration (Zhao et al., 2015). The stretching vibration of C=O give the peak at 1745 cm^{-1}, while the peak at 1643 cm^{-1} was assigned to aromatic CH bonds (Zhao et al., 2015). The peak at 1077 could be related to the C-O stretching vibration of fibers (Singha et al., 2019). The protein band (1700–1600 and 1570–1534 cm^{-1}) was observed at 1745 cm^{-1}. The presence of a peak at 1745 cm^{-1} may be due to the pectin content in enriched samples, which were supplemented with seedless grape pomace (Amador-Rodríguez et al., 2019). C-O and C-C stretching of xyloglucan could give the peak at 1077 cm^{-1} (Amador-Rodríguez et al., 2019).

The nutritional profile of the fortified snacks compared to the control are showed in Table 3. It can be observed that the amount of nutrients (protein, ash, lipids, and fiber) increased significantly after grape pomace addition.

Table 3

Nutritional profile of extruded corn snacks with white seedless grape pomace (SGPWO) and red seedless grape pomace (SGPRO) *vs.* control (C)

Sample	SGPWO	SGPRO	C
Protein (% d.b.)	8.78 ± 0.03^b	9.58 ± 0.02^a	7.61 ± 0.02^c
Ash (% d.b.)	1.63 ± 0.01^a	1.34 ± 0.01^b	0.45 ± 0.01^c
Moisture (% d.b.)	6.57 ± 0.01^c	8.02 ± 0.02^b	8.33 ± 0.02^a
Lipids (% d.b.)	1.48 ± 0.05^b	1.70 ± 0.06^a	0.35 ± 0.07^c
Fiber (% d.b.)	17.08 ± 0.03^a	10.67 ± 0.14^b	0.46 ± 0.19^c
AA DPPH (%)	93.68 ± 0.10^a	91.73 ± 0.10^b	38.04 ± 0.10^c

Mean values followed by different letters in the same row are significantly different ($p < 0.05$)

The extruded corn snacks with red seedless grape pomace (SGPRO) presented higher protein and lipids content, while the extruded corn snacks with white seedless grape pomace (SGPWO) exhibited the greatest ash and fiber content. Significanlty higher ($p < 0.05$) antiradical activity was observed in the snacks with SGPWO presenting the greatest value. Drozdz et al. (2014) also reported higher antioxidant activity when corn snacks were enriched with apple and rosehip pomaces. Similar increase in protein, ash, fiber and protein content was reported for corn-based snacks with grape pomace (Yu et al., 2018) due to the intake of nutrients from the ingredients incorporated.

Conclusions

Seedless grape pomace can be incorporated in food formulations to increase the fiber and nutrients content. The suitability of this ingredient for the production of corn snacks at the recommended levels of 30% for the white variety and 20% for the red variety has been demonstrated without significant adverse effects on the quality and acceptability of the final product. The enriched snacks presented higher nutrients content, antioxidant activity and they were richer in some polyphenols like luteolin, quercetin, and myricetin compared to control, depending on the grape variety used. Even if the incorporation of seedless grape pomace determined the reduction of porosity, L*, texture parameters including crispness, and functional properties as the addition level increased, at the recommended doses the quality of the snacks is acceptable and the nutritional benefits are superior. In conclusion, seedless grape pomace is a promising ingredient for the development of new ready to eat healthy food like extruded snacks, with simultaneous benefits for environment protection.

Patent. The results were first used in a patent application entitled "Process for obtaining an extruded non-gluten product, direct-expanded and product so obtained", no. 24464010.8/ep24464010 from 14.11.2024 ("Procedeu de obţinere a unui produs aglutenic extrudat, direct-expandat şi produs astfel obţinut" no. a/00678 from 07.11.2024).

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