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Sensory profile and consumer acceptability of third generation snacks from colored flesh potatoes

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ABSTRACT

The study evaluated the effect of organic acids (citric, lactic, *L*-ascorbic, malic, and *L*-tartaric) on the stabilization of the color of third-generation potato snacks obtained from dried potatoes of varieties with "red" (Mulberry Beauty) and "purple" (Double Fun) flesh. Descriptive and affective sensory analyses were conducted using trained and consumer panels, respectively. The use of organics acids was successful in avoiding the degradation of the main anthocyanins especially in purple (petunidine-3-*p*-cumaroylrutinoside-5-glucoside and malwidine-3-*p*-cumaroylrutinoside-5-glucoside) snacks. Organic acids slightly changed the sensory profile of the potato snacks by increasing some key attributes such as sourness, aftertaste, hardness and crispiness. Red snacks were considered as having a more natural color than purple ones and this perception resulted in higher liking, preference and willingness to buy. The consumer segment more interested in consuming this type of snacks were the young ones, age 18–24. A pretreatment with organic acids (*L*-ascorbic or malic acids) is strongly recommended when preparing third-generation snacks from colored flesh potatoes.

1. Introduction

Potato snacks are a food product well-known and liked by many consumers worldwide; they can be classified as salty snacks. The raw material for their production may be (*i*) raw tubers for production of traditional snacks, or (*ii*) dried raw or cooked potatoes for production of third-generation snacks, which are characterized by a crispy texture, low specific weight and a porous expanded structure. They are produced by expanding pellets in hot oil, air or under the influence of microwaves, increasing their initial volume by 3–8 times (Lusas & Rooney, 2001). Pellets, which are an intermediate product for the production of third-generation snacks, are produced by low-temperature extrusion of dough, consisting of ~60–65 g/100 g potato starch, and dried potatoes and additives, e.g., salt.

The European snacks market is very diverse and consumer preference for salty snacks is very specific and may differ among countries. For example, Poles are most likely to eat traditional potato chips, but they also like to try new products, and therefore are also very open to new snack flavors (Kierunekspozywczy.pl, 2015). The main factor driving consumer preference for snacks at the European scale is taste; this was the main criteria indicated by Italian (56 %), Spanish (57 %), French (62 %), Polish (65 %) and German (70 %) consumers (Jawis, 2024). The growing popularity of ready-made crispy snacks and snack bars among consumers in European countries is becoming an argument for the growth of the snacks market in Europe (Mordorinteligence, 2024). The countries with the highest consumption of potato chips are (i) Germany, 487000 t, (ii) Italy, 249000 t, and (iii) France, 246000 t; these three countries account for 53 % of total consumption. These countries are followed by Netherlands, UK, Spain, Sweden, Portugal, Belgium, Romania, Poland, and Finland, representing 38 % of total consumption (GlobalTrade, 2024).

Consumers increasingly expect not only convenience but also health benefits from snacking. Natural and organic snacks are becoming popular, and their appearance, including color, as well as the fact that

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natural ingredients are used in their production, are of great importance to consumers. This trend includes third-generation snacks made from dried colored flesh potatoes (Nemś et al., 2015; Nemś & Pęksa, 2018). Potatoes are a rich source of substances with antioxidant activity in human nutrition, such as polyphenols, ascorbic acid, and also α-tocopherol and β-carotene, patatin protein fractions, peptides and minerals. Potato varieties with colored flesh, in addition to the typical ingredients, also contain anthocyanins, which are responsible for their intense color. In this way, for example purple potatoes contain similar amounts of anthocyanins to cranberries, and more than red cabbage or red radishes (Jansen & Flamme, 2006), and, compared to white potatoes the antioxidants content may be up to 2–3 times higher (Brown, Wrolstad, Durst, Yang, & Clevidence, 2003). Besides, it was demonstrated that these high anthocyanin contents in purple-fleshed potatoes were reflected in higher antioxidant capacity (Lachman et al., 2009; Lachman, Hamouz, & Orsák, 2016). Finally, it was also demonstrated that the anthocyanin pigments found in red-fleshed varieties are more resistant to technological factors (e.g., heat) during processing, contributing to commercial products with natural and intense colored snacks (Nemś, Kita, Sokół-Łętowska, & Kucharska, 2020). However, to optimize the final color of the commercial snacks, it can be interesting to minimize degradation reactions of the anthocyanins (Nemś & Pęksa, 2018). In this way, preserving and stabilizing the natural color of colored-fleshed potatoes or intermediate ingredients may require additional treatments to the initial blanching step in hot water that prevents browning (Rytel et al., 2019; De Aguiar Cipriano, Ekici, Barnes, Gomes, & Talcott, 2015). Lowering the pH of the food matrix by adding organic acids has a beneficial effect as anthocyanins are particularly resistant to degradation under acidic conditions, because they are present in the form of the flavylium cation, which is their most stable form (Nemś et al., 2020).

Considering all the above, the effect of adding five different organic acids (citric, lactic, ascorbic, malic and tartaric acids) to minimize the color degradation of purple (Mulberry Beaty cultivar) and red (Double Fun cultivar) colored potatoes during the production of third-generation potato snacks was assayed, by evaluating (*i*) CIE$L^*a^*b^*$ color coordinates, (*ii*) descriptive sensory profile, and (*iii*) consumer liking as affected by consumer age.

2. Material and methods

2.1. Raw materials

The materials used for the study were samples of third-generation snacks prepared using dried raw potatoes (grits) of varieties with colored flesh, expanded from extruded pellets in hot oil. To produce these snacks, dried whole unpeeled potato tubers of two varieties with colored flesh were used (*i*) Mulberry Beauty, with red flesh, and (*ii*) Double Fun, with purple flesh. Potatoes were from the 2021/2022 growing season, and were directly purchased from a local producer in Wrocław (Poland). These two potato varieties were selected as model for the two main groups (red and purple) being widely used in the food industry; of course, to generalize the results here a higher number of varieties should be used in further studies.

Potato grits were blanched in hot water and the preservation of their color was evaluated after using five different food organic acids and compared with the control sample blanched only using water (no organic acid addition). Five organic acids of analytical purity, used were: (*i*) citric acid, (*ii*) lactic acid, (*iii*) *L*-ascorbic acid (from now on ascorbic acid), (*iv*) malic acid and (*v*) *L*-tartaric (from now on tartaric acid); these products were purchased from Sigma-Aldrich. Refined rapeseed oil for frying was obtained from the retail market (Bunge Polska, Poland). In the potatoes used for the study, the starch content was determined indirectly by measuring the specific gravity of tubers and reading the starch value from Maercer tables, according to the methodology described by Houghland (Houghland, 1966). In addition to the experimental dried potatoes, potato starch was obtained from a starch factory in Niechlów (Poland), corn grits were obtained from Sante (Poland) and NaCl from Kłodawa (Poland); these ingredients were used to produce potato pellets.

2.2. Technology of dried potato grits production and pellets

Washed, unpeeled potatoes intended for the preparation of experimental dried potatoes were cut into 1.0 cm thick slices using a mechanical slicer (Robot coupe CL, Germany). Then, they were blanched in water at 75–80 °C for 10 min. The hot slices were cooled in ice water (2 min), then, the slices were divided into equal parts by weight, and were immersed for 5 min in parallel in water (control sample) or 1 g/100 g solutions of the five listed organic acids (10 g of each acid in 1 L of solution). The potato slices obtained in this way were frozen at −32 °C and, then, dried in a Christ Alpha 1–4 LSCplus freeze dryer at 25 °C for 24 h. The vacuum level was 0.22 mbar and the condensing temperature was −56 °C. Finally, the dried samples were grounded using a laboratory grinder (Retsch GM 200, Germany) and, then, passed through a 1 mm × 1 mm sieve. The obtained dried potatoes in the form of grits were used as an ingredient of pellets, according to the technology described by Nemś et al. (2015).

2.3. Technology of extruded pellets production

Pellets were produced using a low-temperature extrusion method from a dough with a moisture of 35 g/100 g, consisting of a mixture of potato starch (680 g/kg of the mixture), colored dried potato grits (260 g/kg of the mixture), corn grits (50 g/kg of the mixture) and salt, NaCl (10 g/kg mixture). Before extrusion, the prepared dough was twice passed through a 1 mm × 1 mm sieve. Dough samples were kept at 20 ± 2 °C, packed in polyethylene bags to obtain uniform moisture, and, then, subjected to the extrusion process in a laboratory single-screw extruder from Brabender, model DN 20 (Duisburg, Germany). The compression ratio was 1:1, the screw rotation speed was 120 rpm, and the process temperature in three subsequent sections of the extruder was 50, 60 and 80 °C, respectively. A head with nozzle dimensions of 80 × 0.5 mm was used. The extruded product, in the form of a strip, was cut into pieces measuring 30 × 15 mm and dried at a temperature of 20–22 °C to a moisture 11–12 g/100 g (~14–16 h). Ready-made semi-finished products (pellets) were stored for 1–2 d in tightly closed polyethylene bags, at room temperature, until expanded snacks were obtained from them.

2.4. Expansion methods of experimental pellets into pellet snacks

The process of frying the pellets was carried out in rapeseed oil heated at 180 °C. Samples were removed from the frying matrix after floating 3 s on the surface of the oil. Samples of fried snacks were drained of excess oil on filter paper, left to cool down at room temperature and immediately packed under vacuum conditions for study in both Poland and Spain.

2.5. Physico-chemical analyses

In raw tubers, the dry weight was determined by drying the samples at 102 °C until a constant weight was achieved (Latimer, 2023) and the anthocyanin content in the raw material was quantified using the HPLC-PDA method, as described by Nemś et al. (2015). The snacks color was expressed using the CIE$L^*a^*b^*$ space, lightness (L^*), a^* (green-red coordinate) and b^* (blue-yellow coordinate), as well as the hue angle (h°) and chroma (C). These color parameters were obtained using a Konica Minolta CR 300 spectrophotometer (Osaka, Japan). Analysis was conducted in five different snacks and in three position within each snack (15 replications). The ready-made snacks were subjected to sensory evaluation using descriptive sensory analysis (trained panel) and affective sensory analysis (consumer panel).

2.6. Descriptive sensory analysis

Six trained panelists (4 males and 2 females) from the Food Quality and Safety Group (*Escuela Politécnica Superior de Orihuela*) of the *Universidad Miguel Hernández de Elche* (Orihuela, Alicante, Spain), selected, trained and validated according to ISO standard 8586-1 (ISO, 2012; Meilgaard, Civille, & Carr, 2016), performed the sensory analyses. Prior to carrying out the determinations of the samples under study, the panel worked for 2 days developing the lexicon and standardizing the references to be used, which were the basis for the test questionnaire (Supplementary Tables 1-2). The scale used ranged from 0 (no intensity) to 10 (extremely high intensity) with 0.5 increments. The panel analyzed the following attributes:

– Appearance: irregularity, color, color homogeneity, and structure.
– Flavor: sweet, sour, salt, bitter, potato ID, organic acid (lactic, tartaric, malic, citric, ascorbic), fried, and aftertaste.
– Texture: hardness, crispiness, structure, graininess, solubility in mouth, and tooth packing.

Once developed, all samples (in triplicate) were analyzed in 2 tasting sessions; data is provided as the mean value ± standard error. The samples were served in plastic containers (transparent and odor-free), coded with random 3-digit codes. The sensory panel was performed under controlled environmental conditions (light 70–90 fc, temperature of 22 ± 2 °C) in individual normalized booths.

2.7. Affective sensory analysis

Snacks prepared using malic acid were those selected for the affective studies based on having intermediate sensory profile, without having any significant imbalance and intermediate intensities of sweetness, sourness, saltiness, potato-ID, aftertaste, hardness, and crispiness. Snacks were prepared at the Wrocław University of Environmental and Life Sciences, were vacuum-packed and immediately posted to Spain; the studies in Poland and Spain were conducted simultaneously.

The affective study was done using 137 consumers [65 Alicante (Spain) and 72 Wrocław (Poland)]; email and flyers were used for the recruitment process; the only requirement for the participants was that they should be frequent consumers of snacks. The consumer profile considering "age" as the only factor was 49, 47 and 41 for the age ranges 18–24, 25–39 and > 40 years old, respectively. The main aim of the current study was to evaluate the effects of the "potato variety" and "age" factors on consumer liking; in a future study, the "country" factor will be studied.

The study was conducted in Summer 2023, during morning time and the recruitment was done at two campuses (Orihuela and Alicante) of the Universidad Miguel Hernández de Elche (Spain) and Wrocław University of Environmental and Life Sciences (Poland); participants belonged to different categories within the universities, such as students, teachers, maintenance staff, etc. Consumer tests were conducted in individual portable normalized booths under controlled environmental conditions, reproducing as much as possible the conditions used in descriptive tests (light 70–90 fc, temperature of 22 ± 2 °C).

Consumers were asked about their liking for each of the main sensory attributes (overall, color, odor, flavor, sweetness, saltiness, fried flavor, aftertaste, hardness and crispiness), using a nine-point hedonic scale (1 = dislike extremely; 5 = neither like or dislike; and 9 = like extremely) and their basic demographic information (gender and range of age). Besides, the questionnaire included questions about sample preference and reasons supporting this selection, willingness to buy the product, and food habits especially regarding snacks consumption (frequency of consumption and location of this consumption). The preference test asked, "which of the samples evaluated was the preferred one?" Thus, consumers should choose only one of the samples evaluated. Then, a CATA table presented the main snack attributes potentially supporting consumer preference; the proposed attributes were randomly presented to each consumer.

The test questionnaire was developed in Spanish and then, translated into Polish; finally, back translation from Polish to Spanish was conducted to check the proper translation. All samples were served in a randomized order labeled with three-digit codes.

Research was approved by the ethics committee of *Oficina de Investigación Responsable, OIR,* under the reference PRL.DTA.ESN.01.22 (Universidad Miguel Hernández de Elche, Elche, Alicante, Spain) and by the Rector's committee for research ethics (Wrocław University of Environmental and Life Sciences) under the reference N0N00000.0011.5.2024. Moreover, consumers provided their informed consent prior to participating in the study.

2.8. Statistical analysis

The instrumental color and descriptive sensory data were processed only using the factor "organic acid"; however, affective results were processed using a two way variance analysis (factors: "potato variety" and "age"; important to highlight that country was not a factor in this study), followed by the Tukey's multiple range test. Differences were considered statistically significant at $p < 0.05$. The software used to perform the statistical analyses was XLSTAT Premium 2016 (Addinsoft, New York, NY, USA).

3. Results and discussion

3.1. Chemical composition of the potatoes used for potato grits preparation

Raw tubers of both varieties (Mulberry Beauty and Double Fun) had similar (*i*) dry matter content 218 and 222 g/kg, respectively, and (*ii*) starch content 167 and 161 g/kg, respectively. Besides, Mulberry Beauty potatoes contained an average of 1122 mg/kg of total anthocyanins in dry matter, and Double Fun potatoes 2317 mg/kg. The dominant anthocyanin in the tubers of the Mulberry Beauty variety was pelargonidine-3-p-cumaroylorutinoside-5-glucoside, with an average content of 845 mg/kg of dry matter (dm). While in Double Fun tubers, two anthocyanins dominated petunidine-3-*p*-cumaroylrutinoside-5-glucoside (1890 mg/kg dm), and malwidine-3-*p*-cumaroylrutinoside-5-glucoside (303 mg/kg dm).

3.2. Influence of organic acids on the organoleptic profile of colored third generation potato snacks

The use of experimental potato grits with intense red (Mulberry Beauty variety) and purple (Double Fun variety) color in the production of potato pellets, instead of traditional potato grits from tubers with yellow flesh, allowed the production of third-generation snacks with an unusual color but "fully natural" red or purple (Fig. 1). As can be seen, the use of the five organic acids at a concentration of 1 g/100 g (acid weight/solution volume) in snacks production had a positive effect on the stabilization of the purple and, to a lesser extent, of red color of the resulting finished products, depending on the acid used and the potato variety.

The control samples of the purple-fleshed Double Fun potatoes had significant less intensity of purple color than samples prepared after using organic acids (statistically significant differences were found for the coordinates a^*, b^*, C^* and Hue); however, the color of the red-fleshed Mulberry Beauty potatoes had a similar color intensity to those treated with organic acids (only statistically significant effects on the L^* coordinate were found).

Some authors confirmed the positive effect of organic acids on maintaining the characteristic color of plant origin products (Song, Ji, Park, Kim, & Hogstrand, 2018). The color of red and purple-fleshed

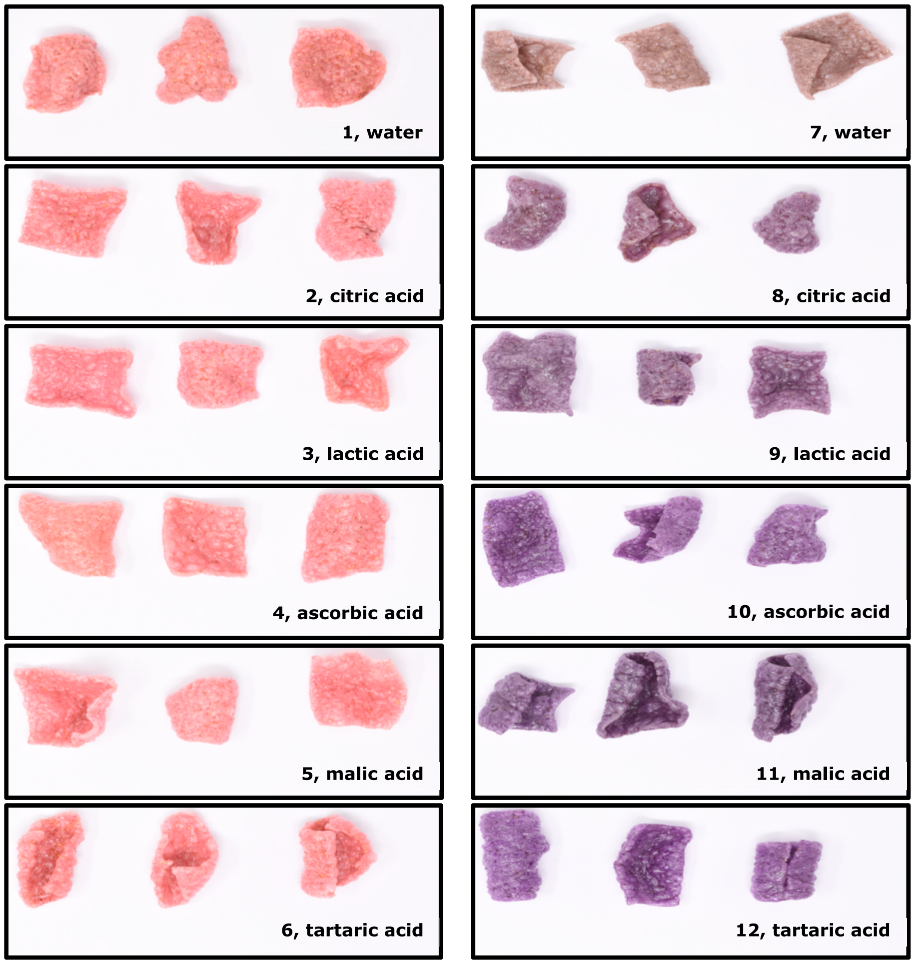

Fig. 1. Third-generation colored potato snacks produced with the use of different organic acids (samples 1–6: produced using dried potatoes of red-flesh cv. Mulberry Beauty; samples 7–12: produced using dried potatoes of purple-flesh cv. Double Fun); samples immersed in (i) water, control, 1 and 7; (ii) citric acid, 2 and 8; (iii) lactic acid, 3 and 9; (iv) ascorbic acid, 4 and 10; (v) malic acid, 5 and 11; and *L*-tartaric acid, 6 and 12.

potato products is influenced by a number of factors. Anthocyanins present in such potatoes may degrade under the influence of processing processes and change depending on pH. So far, the exact mechanism of anthocyanin degradation is unknown. Some studies suggested that under the influence of heating, in the first stage, the glycosidic bonds in the pigment molecule are hydrolyzed and an unstable aglycone is formed. Increased temperature causes the transformation of anthocyanins into colorless chalcones, which are oxidized, creating brown compounds of high molecular weight (Oszmiański, Bąkowska, & Piacente, 2004). The degradation of anthocyanins depends primarily on their structure. The diversity of these compounds results from the large possibilities of attaching hydroxyl and methoxy groups in the flavylium cation ring, as well as from the number and type of substituents. The degree of glycosylation and acylation of anthocyanidin with phenolic or organic acids also influence the improvement of the stability of anthocyanin pigments (Brownmiller, Howard, & Prior, 2008). Colored potatoes contain acylated anthocyanins, whose structure is stable in a wide pH range.

The study used five organic acids to examine their influence on the color of potato snacks containing various types of anthocyanins. Ascorbic, citric, and malic acids are used as safe food ingredients to regulate and maintain appropriate acidity. Margues et al. (2020) demonstrated substantial antioxidant and chelating activity of a 1 g/100 g malic acid solution, as well as a positive effect on stabilizing the consistency of products containing this acid. In this way, citric acid is used in potato processing to increase the antioxidant activity and to avoid browning.

However, the observed differences in the influence of various organic acids on the color of potato products with red and purple flesh are complex. This is influenced by both the transformation of polyphenol compounds activated by PPO (polyphenol oxidase), leading to the formation of brown melanin, and the transformations occurring in anthocyanins under the influence of pH changes, also depending on the type of anthocyanins and their amount (Rytel et al., 2019; Amaral, Benedetti, Pujolà, & Achaerandio, 2018).

Depending on the degree of their degradation, anthocyanins may form colorless chalcones, and in the next reactions oxidize to form high-molecular brown compounds (Oszmiański et al., 2004). It is usually reported that red-fleshed potatoes contain fewer anthocyanins than purple-fleshed varieties and that the main anthocyanins in red potatoes are pelargonidin and its derivatives, while in purple potatoes they are mainly petunidin, malvidin and their derivatives (Nemś et al., 2015). The raw material used for the current study, including Mulberry Beauty potatoes, contained over 840 mg of total anthocyanins per 1 kg of dry matter, of which over 75 % was pelargonidin-3-*p*-coumaroylrutinoside-5-glucoside; on the other hand, Double Fun potatoes with purple flesh contained a total of over 2310 mg of anthocyanins per 1 kg, of which over 94 % were two anthocyanins, petunidin-3-*p*-coumaroylrutinoside-5-glucoside and malvidin-3-*p*-coumaroylrutinoside-5-glucoside.

In the process of producing snacks from the tested potatoes with colored flesh, a blanching process in hot water was used, largely eliminating the browning processes of potato tissue by inactivating the PPO oxidizing enzymes that activate them. Blanching lasting few seconds or minutes is often used in vegetable processing to obtain light-colored products without brown discoloration (Amaral et al., 2018; Severoni, Baiano, De Phili, Romaniello, & Derossi, 2003). In the study by Amaral et al. (2018), the use of citric acid in the production of potato fries prevented browning of cut fries stored in refrigerated conditions before frying. According to these authors, citric acid can be used to prevent browning processes because it inhibits PPO by lowering the pH and chelation of copper to the active site of the enzyme. The color of the evaluated snacks was uniform, with slight variations in intensity and without brown discoloration. It can therefore be concluded that the obtained color of snacks was primarily related to the stabilization of the color of anthocyanins found in studied color-fleshed potatoes in the presence of organic acids.

The use of five different organic acids in the production of snacks from red-fleshed potatoes of the Mulberry Beauty variety did not significantly influence the differentiation of their color expressed by the color parameters a^* and b^* of the CIE$L^*a^*b^*$ system, except the L^* parameter determining the degree of color brightness (at $p < 0.01$). Experimental data (Table 1) showed that the control snacks were significantly darker than the snacks obtained with organic acids. However, regardless of the type of acid used, the obtained products did not differ significantly in terms of brightness.

The organic acids used in the experiment had a different impact on the color of snacks obtained from dried purple potatoes of the Double Fun variety (Table 2). In their case, highly significant effects (at $p < 0.001$) of the type of organic acid used in the experiment on the color shade (Hue angle), its intensity (C*), and the share of red (a^*) and yellow (b^*) coordinates in the measured snack color were noted. However, there was no significant effect of the use of organic acids on the brightness of snacks. The results of color measurements indicated a greater share of red and blue shades in snacks obtained with *L*-ascorbic and *L*-tartaric acids. The remaining snacks made with organic acids showed a similar share of red and blue coordinates. The color intensity of snacks made of purple-fleshed potatoes stabilized with organic acids ranged from 12.1 to 17.5, with samples of products made with tartaric and ascorbic acids having a significantly higher and similar color intensity. Control snacks in which water was used instead of an organic acid solution were characterized by a much less saturated color (9.40). In the study by Song et al. (2018), the use of organic acids in the production of berry juice had a different impact on maintaining the intensity of its color during 10 days of storage, depending on the type of acid. Citric and tartaric acids had the greatest protective effect on the color intensity of berry juice, for example compared to acetic acid.

3.3. Descriptive sensory analysis

A descriptive sensory analysis of the characteristics of the tested third-generation snacks based on dried potatoes of red and purple flesh varieties, Mulberry Beauty and Double Fun, respectively, showed a significant impact of the use of organic acid in their production on appearance, flavor and texture (Tables 3–4); however, there was no significant effect of organic acid on the irregular appearance (non-uniform shape), uniformity of color and structure (degree of expansion) of the obtained snacks.

According to the trained panel, the most distinctive color among red-flesh potato snacks ($p < 0.001$) was that of control products and those in which L-ascorbic acid was used in their production (Table 3). However, the samples prepared with malic and tartaric acids were those having the lowest color intensity.

In general, the levels of bitterness, sourness and sweetness were low (means of 0.3, 1.5 and 2.1, respectively) than those of saltiness (mean of 3.8); this is why these snacks can be classified as salty snacks. However, samples prepared using organic acids showed slightly but significant higher levels of both sourness and sweetness (1.7 and 2.2, respectively) as compared to the control sample (0.6 and 1.7, respectively). The use of lactic acid resulted in sweeter snacks while the use of citric and tartaric acid reduced the intensity of the potato-ID flavor. The addition of organic acids increased the intensity of fried flavor and resulted in longer aftertaste. Regarding texture attributes, snacks prepared using citric acid were harder and crispier than controls. Samples of red snacks prepared with organic acids, especially citric acid, were rated by the panelists as more granular, e.g., with a more noticeable presence of harder particles and less soluble in the mouth than the control products. However, it is worth emphasizing the evaluation results indicating high solubility of all analyzed red snacks (7.0–8.0 scores) and their low tooth packing (2.0–3.1 scores). The texture of fried potato products depends largely on the starch content and dry matter of the potatoes (Lisińska, Pęksa, Kita, Rytel, & Tajner-Czopek, 2009). The potatoes used in the current study were characterized by a similar content of these ingredients, therefore it can be assumed that the physical characteristics of the snacks obtained during the research were differentiated primarily by the organic acids used.

When assessing the color of the purple snacks, the panelists indicated a clear difference ($p < 0.001$) between the snacks from the control treatment and that of the products stabilized with organic acids (Table 4). Differences in purple color within samples prepared using 5 different acids were also easily noticeable. Among them, snacks stabilized with malic acid were rated the more intense (9.3), and snacks stabilized with lactic and citric acid where those with the lowest intensity (5.2–6.4). As in the case of red snacks, the panel pointed out that the use of organic acids (especially citric acid) significantly increased the intensity of the sour taste, as compared to that of the controls. The salty taste was perceived at a lower level (range 2.7–3.5, mean of 3.1) than in red snacks (range 3.6–4.2, mean of 3.8). The use of tartaric acid slightly decreased the intensity of potato-ID flavor, as observed in the red snacks. When assessing the intensity of the fried flavor of purple snacks, the

Table 1
CIE *Lab* color coordinates of third-generation snacks samples obtained from potato grits originated from red fleshed potatoes, cv. Mulberry Beaty.

Sample	L^*	a^*	b^*	C^*	*Hue*
	ANOVA (*p*-value)[a]				
	0.0088	0.0515	0.1036	0.1060	0.0527
	Tukey's Multiple Range Test[b]				
Control (water)	45.5 ± 2.2 b	14.2 ± 0.6	6.8 ± 0.5	15.8 ± 0.7	25.5 ± 1.0
Citric acid	48.8 ± 1.7 ab	14.4 ± 0.6	5.6 ± 0.2	15.5 ± 0.7	21.4 ± 0.5
Lactic acid	51.4 ± 1.4 a	15.7 ± 0.7	5.4 ± 0.4	16.6 ± 0.6	18.9 ± 1.9
L-Ascorbic acid	50.6 ± 1.4 a	15.1 ± 0.5	7.1 ± 1.6	16.7 ± 0.4	25.0 ± 5.6
Malic acid	50.7 ± 1.3 a	15.7 ± 0.8	6.0 ± 0.4	16.7 ± 0.9	20.8 ± 0.3
L-Tartaric acid	49.3 ± 1.4 ab	14.5 ± 0.6	6.3 ± 0.2	15.8 ± 0.5	23.3 ± 1.4

[a] Bold *p*-values are significant at $p < 0.05$.
[b] Values (mean of 15 replications) followed by the same letter, within the same column, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

Table 2
CIEL*a*b* color coordinates of third-generation snacks samples obtained from potato grits originated from red fleshed potatoes, cv. Double Fun.

Sample	L*	a*	b*	C*	Hue
	ANOVA (p-value)[a]				
	0.3748	0.0000	0.0000	0.0000	0.0000
	Tukey's Multiple Range Test[b]				
Control (water)	42.1 ± 3.3	8.01 ± 0.8 c	4.9 ± 0.3a	9.40 ± 0.7c	31.6 ± 3.1c
Citric acid	41.0 ± 1.6	11.9 ± 0.5 b	−3.4 ± 0.8 b	12.4 ± 0.7b	344 ± 2.9a
Lactic acid	40.2 ± 0.3	11.8 ± 0.4 b	−3.6 ± 0.3b	12.4 ± 0.5b	343 ± 0.9a
L-Ascorbic acid	39.1 ± 2.2	14.3 ± 1.9 ab	−7.3 ± 1.3c	16.0 ± 2.3 a	333 ± 1.3b
Malic acid	39.9 ± 1.7	11.1 ± 0.5 b	−5.0 ± 0.6b	12.1 ± 0.6 b	335 ± 2.1 b
L-Tartaric acid	39.0 ± 0.4	15.4 ± 0.3 a	−8.4 ± 0.4c	17.5 ± 0.4a	331 ± 0.7 b

[a] Bold p-values are significant at $p < 0.05$.
[b] Values (mean of 15 replications) followed by the same letter, within the same column, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

Table 3
Descriptive sensory analysis of third-generation snacks samples obtained from potato grits originated from red-fleshed potatoes, cv. Mulberry Beauty. *Values represent the mean values and standard error were always ≤ 0.3 units.*

Attribute	ANOVA (p-value)[a]	Control	Organic acid				
			Citric	Lactic	L-Ascorbic	Malic	L-Tartaric
		Tukey's Multiple Range Test[b]					
APPEARANCE							
Irregularity	1.0000	9.2	9.2	9.2	9.2	9.2	9.2
Color	**0.0000**	7.4 a	5.2 c	4.6 d	6.1 b	3.0 f	3.6 e
Color homogeneity	1.0000	10.0	10.0	10.0	10.0	10.0	10.0
Structure	1.0000	10.0	10.0	10.0	10.0	10.0	10.0
FLAVOR							
Sweetness	**0.0004**	1.7 c	2.1 b	2.5 a	2.1 b	2.3 b	2.3 b
Sourness	**0.0002**	0.6 c	1.8 a	1.6 b	1.7 b	1.8 a	1.7 b
Saltiness	0.8428	4.2	3.8	4.0	3.6	3.8	3.8
Bitterness	0.8887	0.3	0.3	0.3	0.3	0.3	0.4
Potato ID	**0.0020**	7.4 ab	6.8 b	7.9 a	7.2 ab	7.3 ab	6.5 b
Lactic acid	**0.0025**	0.0 b	0.0 b	0.8 a	0.0 b	0.0 b	0.0 b
Tartaric acid	**0.0072**	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.6 a
Malic acid	**0.0019**	0.0 b	0.0 b	0.0 b	0.0 b	0.5 a	0.0 b
Citric acid	**0.0009**	0.0 c	0.9 a	0.1 c	0.1 c	0.1 c	0.7 b
Ascorbic acid	**0.0060**	0.0 b	0.3 ab	0.0 b	0.7 a	0.0 b	0.0 b
Fried	**0.0021**	2.8 b	3.4 ab	3.3 ab	3.8 a	3.8 a	3.3 ab
Aftertaste	**0.0052**	4.0 b	4.1 b	4.8 a	4.4 ab	4.8 a	4.7 a
TEXTURE							
Hardness	**0.0078**	7.8 b	8.8 a	8.0 ab	8.2 ab	8.1 ab	8.8 a
Crispiness	**0.0483**	9.2 b	9.6 a	9.0 b	9.0 b	9.0 b	9.3 b
Structure	0.5500	9.8	9.8	8.3	9.8	9.8	9.8
Graininess	**0.0087**	2.8 b	4.2 a	3.3 ab	3.5 ab	3.8 ab	3.7 ab
Solubility in mouth	**0.0022**	8.0 a	7.0 b	7.6 ab	7.3 ab	7.4 ab	7.7 ab
Tooth packing	**0.0027**	2.0 b	3.1 a	2.3 ab	2.8 ab	2.7 ab	2.8 ab

[a] Bold p-values are significant at $p < 0.05$.
[b] Values (mean of 6 trained panelists) followed by the same letter, within the same row, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

panelists showed a more noticeable taste in snacks stabilized with organic acids, especially tartaric acid, than in the control sample. The panel also found that purple snacks made with organic acids have a longer aftertaste than the control products. When assessing the texture profiles, the panelists considered the purple snacks to be hard and very crispy, but the use of organic acids in their production did not have a clearly different effect on these characteristics of the snacks.

3.4. Affective sensory study

Acceptance studies on the sensory characteristics of third-generation fried potato snacks made from potatoes with red and purple flesh were conducted among consumers of two countries (Spain and Poland); although the two factors under study were "potato variety" [with red (Mulberry Beauty) or purple (Double Fun) flesh color] and "age", with three groups: (*i*) 18–24, (*ii*) 25–39, and (*iii*) above 40 years old. The normality of the data distribution was checked using the Shapiro-Wilk test and it was demonstrated that in this particular case, and perhaps due to the big differences among the studied samples, the variables under study followed normal distributions (Supplementary Table 3).

Regarding the factor "potato variety", red snacks were like more than the purple ones and this higher overall liking was linked to a slight but significant higher liking scores for most of the evaluated sensory attributes (color, odor, flavor, saltiness, and fried flavor) (Table 5). This result was also supported by the preference test in which 55 % of the consumers preferred the Mulberry Beauty snacks. When consumers were asked about why they preferred the selected sample, they indicated that the two most important drivers of the selection were aftertaste (68 % of

Table 4
Descriptive sensory analysis of third-generation snacks samples obtained from potato grits originated from purple-fleshed potatoes, cv. Double Fun. *Values represent the mean values and standard error were always ≤ 0.3 units.*

Attribute	ANOVA (*p*-value)[a]	Control	Organic acid				
			Citric	Lactic	*L*-Ascorbic	Malic	*L*-Tartaric
		Tukey Multiple Range Test[b]					
APPEARANCE							
Irregularity	1.0000	9.2	9.2	9.2	9.2	9.2	9.2
Color	**0.0000**	4.0 d	5.2 cd	6.4 c	7.9 b	9.3 a	7.9 b
Color homogeneity	1.000	10.0	10.0	10.0	10.0	10.0	10.0
Structure	1.0000	10.0	10.0	10.0	10.0	10.0	10.0
FLAVOR							
Sweetness	**0.0074**	2.5 a	2.2 b	2.3 b	2.2 b	2.3 b	1.9 b
Sourness	**0.0006**	0.6 c	2.3 a	1.7 b	1.7 b	1.2 b	1.2 b
Saltiness	**0.0068**	2.7 b	3.1 ab	3.5 a	3.4 a	2.8 ab	2.9 ab
Bitterness	**0.0011**	0.1 b	0.3 b	0.2 b	0.1 b	0.1 b	0.9 a
Potato ID	**0.0031**	7.4 ab	7.3 ab	7.3 ab	8.0 a	7.6 ab	6.2 b
Lactic acid	**0.0042**	0.0 b	0.0 b	0.8 a	0.2 ab	0.0 b	0.0 b
Tartaric acid	**0.0001**	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	1.1 a
Malic acid	**0.0088**	0.0 b	0.0 b	0.0 b	0.1 b	0.7 a	0.1 b
Citric acid	**0.0026**	0.0 b	1.2 a	0.3 ab	0.2 b	0.2 b	0.0 b
Ascorbic acid	**0.0480**	0.0 b	0.3 b	0.0 b	0.8 a	0.1 b	0.3 b
Fried	**0.0004**	2.8 c	3.7 b	3.3 b	3.5 b	3.8 b	4.1 a
Aftertaste	**0.0012**	3.8 b	4.3 ab	4.7 a	4.9 a	4.4 ab	4.3 ab
TEXTURE							
Hardness	**0.0085**	8.1 ab	8.8 a	7.8 b	8.3 ab	8.5 ab	7.7 b
Crispiness	**0.0035**	9.0 ab	9.5 a	8.8 ab	9.2 ab	8.8 ab	8.6 b
Structure	0.2705	10.0	9.3	9.8	10.0	9.7	10.0
Graininess	0.7670	3.8	3.7	3.4	3.6	3.3	3.1
Solubility in mouth	0.9993	6.8	6.8	7.0	6.8	6.6	7.1
Tooth packing	**0.0059**	2.4 b	3.6 a	2.6 ab	3.0 ab	2.8 ab	2.4 b

[a] Bold *p*-values are significant at $p < 0.05$.
[b] Values (mean of 6 trained panelists) followed by the same letter, within the same row, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

Table 5
The effect of two factors (potato variety and age) on overall consumer liking and consumer liking on the most relevant organoleptic characteristics of third-generation snacks samples obtained on the base of potato grits originated from red and purple-fleshed potatoes. *Values represent the mean values and standard error were always ≤ 0.2 units.*

	Overall	Color	Odor	Flavor	Sweetness	Saltiness	Fried flavor	Aftertaste	Hardness	Crispiness
ANOVA (*p*-value)[a]										
Variety	**0.0000**	**0.0430**	**0.0044**	**0.0310**	0.1269	**0.0104**	**0.0118**	0.0877	0.3110	0.2298
Age	**0.0009**	0.0620	**0.0001**	**0.0004**	0.0754	**0.0059**	0.836	**0.0055**	**0.0087**	0.0525
Variety × Age	**0.0000**	**0.0123**	**0.0000**	**0.0000**	0.1849	**0.0465**	**0.415**	**0.0390**	**0.0003**	**0.0478**
Tukey's Multiple Range Test[b]										
VARIETY										
Red	6.7 a	7.2 a	6.2 a	6.4 a	5.9	6.5 a	5.8 a	6.1	6.7	6.9
Purple	6.1 b	6.9 b	5.7 b	6.0 b	5.8	6.2 b	5.4 b	5.9	6.4	6.6
AGE										
18–24	6.9 a	7.3	6.3 a	6.7 a	5.7	6.7 a	5.6	6.3 a	7.0 a	7.0
25–39	6.4 ab	6.9	5.5 b	6.1 b	5.8	6.2 b	5.5	5.7 b	6.3 b	6.5
40–74	6.0 b	7.0	6.0 ab	5.9 b	6.1	6.1 b	5.8	5.9 ab	6.5 b	6.8
VARIETY × AGE										
Red × 18-24	7.2 a	7.6 a	6.6 a	7.0 a	5.9	6.9 a	5.9 ab	6.5 a	7.0 a	7.3 a
Red × 25-39	7.0 a	7.4 a	5.6 b	6.2 b	5.8	6.4 ab	5.4 b	5.7 b	6.8 a	6.7 ab
Red × 40-74	6.0 b	6.7 b	6.3 ab	6.0 b	6.2	6.2 ab	6.2 a	6.0 ab	6.4 a	6.9 ab
Purple × 18-24	6.6 a	7.1 a	6.0 ab	6.4 ab	5.5	6.5 ab	5.4 b	6.1 ab	7.0 a	6.7 ab
Purple × 25-39	5.8 b	6.4 b	5.3 b	5.9 b	5.7	6.0 b	5.5 b	5.7 b	5.9 b	6.4 b
Purple × 40-74	5.9 b	7.2 ab	5.7 b	5.8 b	6.1	6.0 b	5.4 b	5.8 b	6.5 a	6.7 ab

[a] Bold *p*-values are significant at $p < 0.05$.
[b] Values followed by the same letter, within the same column and factor, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

the consumers) and color (50 % of consumers). It is important to highlight the fact that consumers considered "color" as one of the two drivers influencing consumer preference.

Finally, 88 and 72 consumers (64.2 % versus 52.6 %, respectively) concluded that they were willing to buy the snacks prepared using red- or purple-colored potatoes, respectively.

The lower values of overall liking, preference and willingness to buy the purple potato snacks can be related to a high consumer perception

(47 % of consumers) of these snacks not having a natural color (consumers described these snacks as "not looking natural"). The fact that purple snacks do not look natural has demonstrated to play a key role in determining consumer liking and preference and needs further attention to convince consumers that the color of these snacks come from a natural raw material.

On the other hand, regarding the factor "age", the young consumers showed higher liking scores for overall opinion, odor, flavor, saltiness, aftertaste and hardness. The fact that young consumers are willing to try new foods is supported by recent studies on different food matrixes. For instance, Jacobs et al. (2024) indicated that young consumers are particularly interested in the consumption of artificial meat and how protein, meat and its alternatives are produced in the future. However, no significant differences were observed among the liking scores of the groups 25–39 and 40–74, with the exception of odor.

Finally, it is important to highlight that the youngest consumers (18–24 years old) showed a higher preference for colored snacks which can be related to the fact that they have previously tried potatoes of different colors (purple and red) in a higher proportion than the other two groups (59 %, 38 % and 23 % for 18–24, 25–39 and > 40 years old, respectively).

4. Conclusions

The activity of the organic acids used in the research towards anthocyanins occurring in potatoes of red and purple-fleshed varieties was different. The red color of snacks obtained using dried potatoes of the Mulberry Beauty variety, in which pelargonidin predominated, changed under the influence of acids only to a small extent, barely noticeable organoleptically and not statistically confirmed. Only the color of red snacks made with organic acids lightened compared to the control sample. However, the stabilization of the purple color of snacks made from purple-fleshed potatoes of the Double Fun variety, which is determined by two anthocyanins and their derivatives, such as petunidine-3-*p*-cumaroylrutinoside-5-glucoside and malwidine-3-*p*-cumaroylrutinoside-5-glucoside, required the use of organic acids, regardless of their type. This relationship was confirmed by the results of measurements of the instrumental color of snacks, in which both the color shade (Hue), its intensity (C*), the share of red (a^*) and yellow (b^*) coordinates depended to a large extent on the use of organic acids, and were particularly beneficial after using *L*-ascorbic and *L*-tartaric acids. Sensory data also supported instrumental color data.

Regardless of the potato variety, the use of organic acids to control pH and avoid anthocyanins degradation resulted in slight increases of sourness, fried flavor, and hardness, while they did not affect some of the key attributes such as potato-ID. It was found that citric acid in particular had an impact on increasing the hardness and crispiness of snacks, both red and purple ones, while the best color stabilizer for red snacks was L-ascorbic acid, and for purple snacks was malic acid.

Snacks prepared using Mulberry Beauty red potatoes were preferred to those prepared using Double Fun purple potatoes as they are perceived by consumers as having a more natural color. Results from liking agreed with those of a preference test and willingness to buy. Finally, young consumers (18–24 years old) are the group showing higher consumer acceptance as they are more motivated to try new and innovative products, such as third generation potato snacks.

CRediT authorship contribution statement

Anna Pęksa: Validation, Resources, Methodology, Conceptualization. **Agnieszka Nemś:** Visualization, Methodology, Formal analysis. **Esther Sendra Nadal:** Writing – original draft. **Luis Noguera-Artiaga:** Writing – original draft, Methodology. **Hanán Issa-Issa:** Formal analysis. **Agnieszka Tajner-Czopek:** Writing – original draft. **Ángel A. Carbonell-Barrachina:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Agnieszka Kita:** Writing – original draft.

Informed consent statement

Consumers provided their informed consent prior to participating in the study.

Institutional review board statement

Research was approved by the ethics committee of *Oficina de Investigación Responsable*, OIR, under the reference PRL.DTA.ESN.01.22 (*Universidad Miguel Hernández de Elche*, Elche, Alicante, Spain) and by the Rector's committee for research ethics (Wroclaw University of Environmental and Life Sciences) under the reference N0N00000.0011.5.2024.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2025.117460.

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