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Nutritional Qualities of Different Commercial Raspberries Consumed in Morocco

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ABSTRACT

The dietary habits of the Moroccan population often involve low consumption of fruits and vegetables, coupled with a high intake of fats and sugars, posing a potential risk of diseases such as obesity, diabetes, and cardiovascular diseases. However, red and black raspberries present a healthy and nutritious alternative for Moroccan consumers. This research focuses on the evaluation of the nutritional properties of extracts from seven samples of red and black raspberries commonly consumed in Morocco. Minerals (magnesium, calcium, chloride, phosphorus), glucose, total polyphenols content (TPC), and total flavonoids content (TFC) were determined using spectrophotometric method. Sucrose and fructose contents were determined by a digital refractometer. The results showed variable concentrations of magnesium, calcium, chloride, and phosphorus in the different raspberry samples. The values ranged from 13.40 to 35.50 mg/100g, 52.20 to 98.20 mg/100g, 19 to 33.80 mg/100g, and 27.60 to 37.28 mg/l00g for Mg, Ca, Cl, and P, respectively. The levels of Glucose, Sucrose, and Fructose were between 0.70 to 2.49 g/100g, 0.70 to 1.20 g/100g, and 0.80 to 2.70 g/100g, respectively. TPC, and TFC were between 202 to 301 mg gallic acid equivalents (GAE) per 100g, and 37 to 268 mg Quercetin equivalents (QE) per 100g, respectively. Polyphenol and flavonoid levels were higher in the black raspberry samples than in the red raspberry samples. The results obtained provide adequate data for the classification of different raspberry samples based on their nutritional qualities and provide consumers with an informed choice.

Keywords: Raspberries, Polyphenols, Flavonoids, Minerals, Nutrition

Introduction

Raspberries are edible fruits belonging to various species of Rubus of the Rosaceae family, they are becoming increasingly popular in everyday diet. They come in several colors, including red (*Rubus idaeus L.*) [1], and black *(Rubus occidentalis L.*),[1] and are usually consumed fresh or processed.[2] Several studies have been conducted in Morocco on the agronomic characteristics of raspberry, the expansion of cultivated areas, and pest control measures.[3]
Over the past decade, global fresh raspberry production has grown dynamically, increasing by almost 50% between 2011 and 2020 to nearly 900,000 tons. In Morocco, raspberry production is concentrated in the northern part of the country but has expanded further south, particularly in the semi-arid region of Souss-Massa.[4] In 2022, Moroccan exports of fresh blackberries and raspberries reached a record level, with 56,200 tons exported, representing a 36% increase over the previous year.[5]
Approximately 200 species of red raspberries belong to the subgenus Ideobatus, of which the most popular type is commonly grown. Unlike blackberries belonging to the subgenus Rubus, raspberries have a hollow appearance after picking, leaving behind a finger-like receptacle.[1,6]

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Red raspberries are known for their nutritional value, containing essential nutrients such as vitamins, minerals, soluble fiber, sugars, citric acid, and phenolic compounds.[1,7–13] The bioactive properties and the red-purple color of these fruits are mainly due to their anthocyanin content.[14–17] The main anthocyanins in red raspberries vary according to the cultivars, with cyanidin 3-*O*-glucoside, and cyanidin 3-*O*-sophoroside being the most common.[17–20] These constituents do not only affect the sensory qualities of red raspberries, but also contribute to their health benefits. Studies have demonstrated the potential therapeutic benefits of whole raspberries and their extracts.[16,21,22] This suggests that raspberry consumption may have a positive impact on human health.[1]
Black raspberry (*Rubus coreanus Miquel*) is a plant of the Rosaceae family. It is of growing interest internationally because of its health benefits, including antioxidant, anti-inflammatory, antibacterial, and antiviral properties.[23–28]
The therapeutic effects of black raspberry can be attributed to the many bioactive components it contains, such as flavonoids, tannins, anthocyanins, terpenoids, and phenolic acids.[29] Of these components, anthocyanins are particularly important as they are responsible for the red, purple, and yellow colors of the fruit, and are known for their antioxidant properties. Studies have shown that black raspberries may contain more natural antioxidants than red raspberries.[30]
In Morocco, the nutritional potential of raspberries is yet to be fully harnessed. There is limited research on the nutritional properties of black raspberries specifically in Morocco. This study aimed to investigate the physicochemical properties, mineral, sugar, phenolic, and flavonoid contents of raspberries commonly consumed in Morocco.

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Materials and Methods

Chemicals and reagents

The chemicals used in this study include Glucose GOD PAP reagent, Glucose GOD Standard, Calmagite (1-(1-hydroxy-4-methyl-2-phenylazo)-2-naphthol-4-sulfonic acid), Magnesium Standard, Cresolphthalein Complexone (CPC) reagent, Calcium Standard, Thiocyanate, Chloride Standard, Phosphorus reagent, and Phosphorus Standard (Biolabo, France). Folin-Cioccalteu's reagent, gallic acid, and Quercetin were of Sigma-Aldrich, France. Additionally, sodium nitrite, sodium carbonate and aluminium chloride were of Sigma-Aldrich, Munich, Germany.

Plant materials

The origin and sensory qualities of seven red and black raspberry samples obtained from street vendors in various markets in Morocco are presented in Table 1.

Preparation of Raspberry juice

The different samples of red and black raspberry (10 g each) were washed, and 10 mL of distilled water was added to each sample. The mixture was grinded with the aid of a blender. The mixture was filtered and the extracts obtained were stored at -20°C.

Determination of pH

The pH of the raspberries juice was measured utilizing a pH meter (Sartorius PP-50, Goettingen, Germany).[31]

Determination of water content

The water content of the raspberries was determined following the protocol described by Doymaz (2004).[32] Briefly, 5 g of raspberries were sliced into smaller fragments, and transferred into glass capsules, placed in an oven (Eco therm digital oven, Labotech, South Africa), and heated at 105°C for 3 h. After heating, the capsules were allowed to cool, and their weights were measured until a constant weight was achieved.

Determination of titratable acidity

The titratable acidity of the raspberry juice preparations was determined using a previously described method.[33] This method involves the addition of a 0.1 N NaOH solution until the pH of the juice reaches 8.1, which is sufficient to neutralize the citric acid present in the raspberry juice. The percentage of citric acid was subsequently calculated using a standardized formula as shown below.

$$Titratable\ Acidity\ (\%) = \frac{100 \times VNaOH \times N}{m} \quad (1)$$

Where;

V_{NaOH} is the volume in milliliters (mL) of sodium hydroxide (NaOH) used for titration,

N is the normality in mol/L of NaOH solution used for titration,

m is the weight of the sample in grams (g)

Determination of conductivity

The conductivity of the raspberry samples was measured with a conductivity meter and the result was expressed in microsiemens per centimeter (µS/cm).[34]

Determination of sucrose content

The sucrose content of the raspberries was determined using a digital display hand-held refractometer (Brix) (Hanna Instruments, HI 96801, Rhode Island, USA).[35]

Determination of fructose content

The fructose content of the raspberries was determined by the portable digital display refractometer (Hanna Instruments, HI 96801, Rhode Island, USA).

Determination of glucose content

The concentration of glucose in the raspberries was determined using the enzymatic method.[36,37] This method is based on the oxidation of glucose by glucose oxidase (GOD), resulting in the production of gluconic acid and hydrogen peroxide (H_2O_2). In the presence of peroxidase (POD), hydrogen peroxide reacts with 4-chlorophenol acid phosphate and paraphenylenediamine (PAP), forming a coloured complex. After incubation for 10 min at room temperature, the absorbance of the complex formed was determined at a wavelength of 500 nm. The concentration of glucose in the raspberry juice was determined by comparison with a GOD-PAP glucose standard.

Determination of magnesium content

The magnesium content was determined using the Calmagite method.[38,39] In this method, the reaction medium was incubated at room temperature for 5 min. Calmagite reacts with magnesium in an alkaline environment to form a complex. The absorbance of the complex was measured at a wavelength range of 510-550 nm using a spectrophotometer (UV–VIS, Biobase BK-D560; China). The concentration of magnesium in the samples was determined by comparing with a magnesium standard (20 mg/L).

Determination of calcium content

The calcium content in the raspberry juice samples was determined using the Cresolphthalein Complexone (CPC) method as previously described by Moorehead and Biggs (1974).[40] In this method, a 1 mL portion of o-cresolphthalein reagent was complexed with calcium present in the alkaline solution of the raspberry juice, resulting in the formation of a complex that exhibits absorption at a wavelength of 570 nm using a spectrophotometer UV–VIS (Biobase BK-D560; China). The absorbance of the samples was then subtracted from that of the control. The concentration of calcium in the samples was determined by comparing with a calcium standard (100 mg/L).

Determination of chloride content

The chloride concentration in the raspberry samples was measured by colorimetric method as previously described by Florence and Farrar (1971)[41] and Burtis *et al*. (1999).[42] This method involves the reaction of undissociated mercuric thiocyanate with chloride ions present in the samples. This reaction forms undissociated mercuric chloride and free thiocyanate ions. The free thiocyanate ions further react with ferric iron, resulting in the formation of a red-colored complex. The absorbance of this complex is measured at a wavelength range of 400-500 nm using a spectrophotometer UV–VIS (Biobase BK-D560; China). The concentration of chloride in the samples was determined by comparing with a chloride standard (100 mEq/L).

Determination of Phosphorus content

Phosphorus *content* in the raspberry juice was determined using the No Deproteinization Method as described by Daly and Ertingshausen (1974)[43] and modified by Gamst and Try (1980).[44] In this method, the phosphate ions in the juice form a phospho-molybdic complex with ammonium molybdate in an acidic medium. The absorbance of this complex is measured at a wavelength of 340 nm using a spectrophotometer UV–VIS (Biobase BK-D560; China), and the magnitude of the absorbance is directly proportional to the concentration of phosphate ions in the sample.

Determination of total phenolic content

The total phenolic content of the raspberry samples was determined by the Folin-Cioccalteu's method as described by Siddhuraju and Becker (2003).[45] Briefly, 200 µL of the raspberry juice extract was added to 1.5 mL of Folin-Cioccalteu reagent (diluted 10-fold). The mixture was incubated at room temperature for 5 min. Thereafter, 1.5 mL of sodium carbonate solution (60 g/L) was added, and the sample was further incubated in the dark for 90 min. During this incubation period, a blue coloration developed, and the absorbance of the sample was measured at a 725 nm using a spectrophotometer UV–VIS (Biobase BK-D560; China). The concentration of polyphenols present in the raspberry juice was determined using a calibration curve constructed using gallic acid at concentrations ranging from 0 to 200 µg/mL.

Determination of total flavonoid content

The amount of flavonoids present in the raspberry juice samples was determined using the aluminium chloride colorimetric method as previously described.[46, 47] Briefly, 400 µL of the extract was mixed with 120 µL of $NaNO_2$ (5%) and incubated for 5 min, followed by the addition of 120 µL of $AlCl_3$ (10%) and a 6-minute incubation at room temperature. Finally, 800 µL of 1 M NaOH was added and the

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absorbance of the resulting reaction medium was measured at 510 nm using a spectrophotometer UV–VIS (Biobase BK-D560; China)..

Statistical analysis

Data were presented as mean ± standard error of mean of triplicates determination. Statistical analysis was performed using One-way analysis of variance (ANOVA), and statistical comparisons between the Raspberry samples were made using GraphPad Prism version 9.5.1 software. Tukey's test was employed to compare the means obtained, and statistical significance was determined at a significance level of $p < 0.05$.

A Pearson correlation test was conducted to assess the correlation between the parameters identified using SPSS version 21 software.

Results and Discussion

Organoleptic properties of raspberries

Moroccan raspberry samples ranged in colour from purple-red to very bright black. The black and purple raspberry samples were moderately sweet flavored and the red varieties were less sweet and moderately tart (Table 1).

Physicochemical properties of the different raspberry samples

The results of the physicochemical parameters of the seven raspberry samples (1 - 7) are presented in Table 2.

The raspberries studied have a moisture content ranging from 67% to 87%. Sample 4 had the highest moisture content compared to the other raspberry samples, while sample 5 had the lowest moisture content. These results are comparable to that reported by de Souza *et al*. (2014)[7] who reported 88.60% moisture content for red raspberries and higher than that reported by Yang and Choi (2017)[48] where 81.44% moisture content was found in black raspberries. The variations in moisture content can be attributed to various factors such as variety, time of harvest, degree of ripeness, stage of ripening, weather and soil conditions, exposure to sunlight, the position of the fruit on the plant, and the effect of post-harvest treatments on chemical and physical properties.[49]

The pH of the raspberry samples vary from 3.56 to 4.07. The raspberry sample 4 was more acidic than the other red raspberry samples, while the red raspberry samples 2 and 3 from Larache and Casablanca, respectively were less acidic. These pH values are higher than those reported by Vara *et al*. (2020)[1] where pH of 3.29 to 3.43 were reported for red raspberries, and similar to the values reported by Weber`*et al*. (2008),[50] where pH of 3.5 to 3.6 were found for black raspberries. The acidic nature of raspberries is due to the presence of organic acids such as malic acid, and citric acid, the latter being more abundant in raspberries.[51] The Physicochemical characteristics of raspberries, such as colour, pH, and citric acid content, could be influenced by the combined amount of nitrogen and potassium present in the fertilizer applied.[52]

Titratable acidity ranged from 0.81% to 1.02%, with the raspberry sample 4 having the highest acidity compared to the other raspberry samples. These values are similar to the results obtained by Sadik *et al*. (2023)[53] who reported a pH of 1.10 for black raspberries. Additionally, the present results showed higher acidity for red raspberries than that reported by de Souza *et al*. (2014)[7] for red raspberries (1.86%) and lower than that reported by Cavani *et al*. (2023)[54] (2.46%). These results showed that the increase in pH is proportional to the decrease in titratable acidity of raspberries, which can be attributed to climatic conditions and the ripening process of the fruit.[55]

The conductivity of the raspberry samples range from 0.51 mS/cm to 1.05 mS/cm. of all the raspberry samples, sample 4 from Rabat had the highest conductivity, while sample 3 had the lowest conductivity. These values are similar to the values obtained for the electrical conductivity of strawberries (0.86 - 1.07 mS/cm).[56]

Analysis of the results obtained revealed a correlation between pH, titratable acidity, and conductivity of the raspberries, where an increase in pH is associated with a simultaneous decrease in titratable acidity and conductivity (Table 2).

Mineral content of the different raspberry samples

The mineral content of the seven raspberry samples studied are shown in Table 3. The results showed that black raspberry samples are rich in calcium, magnesium and phosphorus.

Table 1: Organoleptic characteristics of the different raspberry samples

Samples	Place of purchase	Raspberry	Aspect	Colour	Taste	Size (cm)	Form
1	Larache	red raspberry	softness	purple red	sweet and sour	1.82	conical
2	Larache	red raspberry	softness	light red	slightly sweet and sour	1.92	conical
3	Rabat	red raspberry	softness	purple red	Sweet and sour	1.5	conical
4	Rabat	black raspberry	softness	high gloss black	sweet flavored	2.5	fleshy
5	Rabat	red raspberry	softness	light red	slightly sweet lemon flavored	1.5	conical
6	Rabat	red raspberry	softness	red	slightly sweet flavored	1.7	conical
7	Rabat	organic raspberry	Juicy	dark purple	slightly sweet lemon flavored	2.3	fleshy

Table 2: Physicochemical properties of the different raspberry samples

Raspberry Samples	Moisture content (%)	pH	Titratable acidity (%)	Conductivity mS/cm
1	80.00 ± 0.90^{a}	3.65 ± 0.04^{a}	0.91 ± 0.01^{a}	0.76 ± 0.01^{a}
2	85.00 ± 1.35^{b}	4.07 ± 0.01^{b}	0.83 ± 0.01^{b}	0.65 ± 0.01^{b}
3	68.00 ± 0.35^{c}	4.08 ± 0.02^{b}	0.81 ± 0.01^{b}	0.51 ± 0.01^{c}
4	$87.00 \pm 0.50^{d,b}$	3.50 ± 0.10^{a}	1.02 ± 0.01^{d}	1.05 ± 0.01^{d}
5	67.00 ± 0.10^{c}	3.60 ± 0.10^{a}	0.94 ± 0.01^{e}	0.82 ± 0.01^{e}
6	81.00 ± 0.30^{a}	3.56 ± 0.01^{a}	0.96 ± 0.01^{e}	0.86 ± 0.01^{f}
7	84.00 ± 0.10^{b}	3.64 ± 0.01^{a}	0.98 ± 0.01^{g}	0.94 ± 0.01^{g}

Data represent the means ± standard error of mean (n = 3). Values with different superscript letters are significantly different ($p < 0.05$).

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The magnesium content ranged from 16.80 mg/100 g to 35.50 mg/100 g. The raspberry sample 4 has a magnesium content of 35.5 mg/100 g, which was the highest compared to the other raspberry samples. This value was also significantly higher than previously reported values for magnesium content in red raspberries (15.96 mg/100 g)[7] and black raspberries (27 g/100 g).[57]
Calcium is considered the most important element in determining fruit quality.[58] The calcium content in the different raspberry samples ranged from 68.6 mg to 98.4 mg per 100 g fresh weight. The calcium content in the raspberry sample 2 was highest (98.4 mg/100 g) compared to the other raspberry samples studied, while sample 5 had the lowest calcium content (52.25 ± 0.01 mg/100 g). The calcium content obtained in the present study was significantly higher than those obtained from previous studies where calcium content of 1.14 mg/100 g was reported for red raspberries[7] and 31 mg/100 g was reported for black raspberries.[57] It should be noted that calcium was the most abundant mineral element in the raspberry samples studied.
The chloride content obtained in the different raspberry samples studied ranged from 18.02 mg to 83 mg per 100 g fresh weight. Sample 2 from Larache showed a significantly higher chloride content than the other raspberry samples.
The Mg, Ca and Cl contents of red and black raspberries in the present study were higher than those obtained for strawberries.[56]
The phosphorus content in the raspberry samples ranged from 27.60 mg to 38.7 mg per 100 g fresh weight. The black raspberry sample 4 displayed a phosphorus content of 38.7 mg per 100 g, a value that was significantly higher than the phosphorus content in all the other red raspberry samples. This value is similar to that previously reported for black raspberries (36 mg per 100 g)[57] and significantly higher than that reported by de Souza *et al*. (2014)[7] for red raspberries (5.70 mg per 100 g).
Growing raspberries in soil with high levels of mineral elements could affect the amount of minerals absorbed by the plant and subsequently the mineral composition of its fruits.[59] Climatic conditions such as sunshine, temperature and humidity can also affect the mineral content of the fruits. Storage conditions such as prolonged exposure to heat or light can alter the mineral quality of the fruits.[60,61]

Sugar content of the different raspberry samples
The sugar (glucose, sucrose, and fructose) contents of the seven raspberry samples studied are presented in Table 4.
Sugar concentration has a strong influence on the aroma and taste of raspberries. The content of free sugars studied ranged from 0.70 to 2.49 g/100 g, 0.60 to 1.20 g/100 g, and 0.80 to 2.70 g/100 g, for glucose, sucrose, and fructose, respectively. Sample 1 of red raspberries from Larache showed the highest content of free sugars, followed by sample 4 of black raspberries from Rabat, while sample 2 from Larache showed the lowest content of free sugars. Statistical analysis showed that the sucrose content is similar for red and black raspberries. These values are higher than the values obtained in the study of by Vara et al. (2020).[1] who reported values of 2.42 g/100 g, 2.13 g/100 g, and 1.41 g/100 g, for fructose, glucose, and sucrose, respectively in red raspberries. Based on these results, samples 4 and 1 were found to be high in glucose and fructose, while also presenting high concentrations of minerals such as magnesium and calcium. In contrast, sample 5, which displayed low sugar content also presented low calcium and magnesium contents. These results show that red and black raspberries are less sweet compared to other fruits such as blackberries, and blueberries[7] but comparable to strawberries.[56]

Table 3: Mineral content of the different raspberry samples

Raspberry Samples	Mg (mg/100 g)	Ca (mg/100 g)	Cl (mg/100 g)	P (mg/100 g)
1	16.8 ± 0.10 ^{a}	93.20 ± 0.10 ^{a}	21.30 ± 0.10 ^{a}	33.80 ± 0.10 ^{a}
2	22.00 ± 1.8 ^{b}	98.30 ± 0.10 ^{b}	83.00 ± 0.40 ^{b}	30.20 ± 0.10 ^{b}
3	26.00 ± 0.75 ^{c}	75.90 ± 0.05 ^{c}	28.20 ± 0.10 ^{c}	27.60 ± 0.10 ^{c}
4	35.50 ± 0.10 ^{d}	88.70 ± 0.10 ^{d}	19.00 ± 0.40 ^{d}	38.70 ± 0.10 ^{d}
5	24.40 ± 0.10 ^{c}	52.25 ± 0.01 ^{e}	18.02 ± 0.01 ^{e}	29.80 ± 0.10 ^{e}
6	13.50 ± 0.10 ^{f}	71.34 ± 0.01 ^{f}	27.90 ± 0.10 ^{c}	30.50 ± 0.10 ^{f}
7	22.20 ± 0.10 ^{b}	68.60 ± 0.10 ^{g}	28.19 ± 0.01 ^{c}	37.30 ± 0.10 ^{g}

Data represent the means ± standard error of mean (n = 3). Values with different superscript letters are significantly different ($p < 0.05$).

The results suggest that the low free sugar content of red and black raspberries compared to other fruits may have significant nutritional and human health benefits. This may include maintenance of blood sugar levels, reduction of the risk of chronic diseases, and promoting a healthy weight.[62]

Table 4: Sugar content of the different raspberry samples

Raspberry Samples	Glucose (g/100 g)	Sucrose (g/100 g)	Fructose (g/100 g)
1	2.46 ± 0.01 ^{a}	1.20 ± 0.10 ^{a}	2.70 ± 0.5 ^{a}
2	0.54 ± 0.01 ^{b}	0.60 ± 0.10 ^{a}	1.90 ± 0,10 ^{b}
3	1.27 ± 0.01 ^{c}	0.80 ± 0.10 ^{a}	1.20 ± 0,10 ^{c}
4	2.49 ± 0.01 ^{a}	1.00 ± 0.10 ^{a}	1.30 ± 0,10 ^{c}
5	0.70 ± 0.01 ^{e}	0.70 ± 0.10 $^{a, e}$	0.80 ± 0,10 ^{e}
6	1.24 ± 0.01 ^{c}	0.90 ± 0.10 ^{a}	1.30 ± 0,10 ^{c}
7	1.02 ± 0.01 ^{g}	0.80 ± 0.10 ^{a}	1.10 ± 0,10 ^{c}

Data represent the means ± standard error of mean (n = 3). Values with different superscript letters are significantly different ($p < 0.05$).

Polyphenol and flavonoid contents of the different raspberry samples
The results of the polyphenol and flavonoid contents of the red and black raspberries studied are presented in Table 5.

Table 5: Polyphenol and flavonoid contents of the different raspberry samples

Raspberry Samples	Polyphenol (mg GAE/100 g)	Flavonoid (mg QE/100 g)
1	279.00 ± 0.90 ^{a}	184.00 ± 0.90 ^{a}
2	256.00 ± 0.90 ^{b}	152.00 ± 0.50 ^{b}
3	286.20 ± 0.10 ^{c}	153.39 ± 0.04 ^{c}
4	307.10 ± 0.10 ^{d}	261.80 ± 0.10 ^{d}
5	270.00 ± 0.90 ^{e}	155.20 ± 0.10 ^{e}
6	301.70 ± 0.10 ^{f}	178.39 ± 0.01 ^{f}
7	202.10 ± 0.10 ^{g}	111.20 ± 0.10 ^{g}

Data represent the means ± standard error of mean (n = 3). Values with different superscript letters are significantly different ($p < 0.05$).

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Phenolic compounds in raspberries have been studied for their potential role in preventing inflammation, oxidative stress, cardiovascular diseases, cancer, type 2 diabetes, and obesity, making them nutritionally beneficial constituents for human health.[63]
The levels of polyphenols in the different raspberry samples studied ranged from 202.00 mg to 307.10 mg per 100 g. The polyphenol content in raspberry sample 4 (307.10 mg/100 g) was higher than the other raspberry samples studied, while the raspberry sample 7 had the lowest polyphenol content. The observed variability in the polyphenol content could be attributed to the differences in the environmental conditions such as light intensity, wavelength and temperature which are associated to the cultivation period as well as the cultivation location.[64]
The polyphenol content obtained in this study is lower compared to values obtained by previous researchers who reported values of 357.83 mg/100 g for polyphenol content in red raspberries,[7] and 362 mg/100 g for polyphenol content in black raspberries.[65]
Raspberries have been shown to possess high antioxidant and anti-inflammatory activities, which are beneficial to health.[66] Consumption of the polyphenols present in raspberries has the potential to provide an alternative treatment for heart failure.[67] The positive impact of this action is evidenced by the reduction in inflammation-related signaling, the decrease in proteins responsible for cardiac remodeling and hypertrophy, and the suppression of phosphorylated ERK1/2, it holds significant importance in signaling pathways linked to cardiac hypertrophy.[67] Studies have revealed these positive effects by demonstrating that raspberry consumption induces a significant improvement in cardiac functional capacity and morphology in an experimental rat model of heart failure.[67] However, to date, no scientific research has been carried out to support these findings in human population.
Raspberry extracts, rich in polyphenolic compounds, have potential curative effects on the inflammation and insulin resistance observed in individuals diagnosed with type 2 diabetes.[68] A recent study observed a significant decrease in levels of high-sensitivity C-reactive protein (hsCRP), a known biomarker for assessing inflammation in individuals with type 2 diabetes following the consumption of raspberry extracts.[68]
The polyphenols obtained from raspberries, from both the flesh and the whole fruit, play a suppressive role in stimulating the NLRP3 inflammasome and act as epigenetic regulators controlling adipocyte development. This action contributes to imparting resistance in obesity and mitigating metabolic dysfunctions associated with dietary patterns. Polyphenolic pulp supplementation increases energy expenditure, mitigates obesity and insulin resistance induced by a high-fat diet, while reducing the recruitment of macrophages in adipose tissue (ATM), suppressing the activation of NLRP3 inflammasome, and adipocyte hypertrophy.[69]

Table 6a: Correlation among Moisture content, pH, Titratable Acidity, Conductivity, Mg, Ca, Cl, P, Glucose, Sucrose, Fructose, Polyphenols, and Flavonoids

		MC	pH	TA	Conduc	Mg	Ca
MC	Pearson correlation	1	-0.251	0.425	0.551	0.044	0.631
	Sig.(two-tailed)		0.586	0.341	0.200	0.926	0.129
pH	Pearson correlation	-0.251	1	-0.945**	-0.889**	-0.016	0.334
	Sig.(two-tailed)	0.586		0.001	0.007	0.973	0.464
TA	Pearson correlation	0.425	-0.945**	1	0.982**	0.206	-0.271
	Sig.(two-tailed)	0.341	0.001		0.000	0.658	0.556
Conduc	Pearson correlation	0.551	-0.889**	0.982**	1	0.263	-0.149
	Sig.(two-tailed)	0.200	0.007	0.000		0.569	0.749
Mg	Pearson correlation	0.044	-0.016	0.206	0.263	1	0.070
	Sig.(two-tailed)	0.926	0.973	0.658	0.569		0.881
Ca	Pearson correlation	0.631	0.334	-0.271	-0.149	0.070	1
	Sig.(two-tailed)	0.129	0.464	0.556	0.749	0.881	
Cl	Pearson correlation	0.337	0.686	-0.570	-0.423	-0.141	0.528
	Sig.(two-tailed)	0.460	0.089	0.181	0.344	0.763	0.223
P	Pearson correlation	0.709	-0.624	0.781*	0.838*	0.390	0.217
	Sig.(two-tailed)	0.075	0.134	0.038	0.019	0.388	0.640
GLU	Pearson correlation	0.318	-0.455	0.402	0.376	0.251	0.437
	Sig.(two-tailed)	0.486	0.304	0.371	0.406	0.587	0.327
SUC	Pearson correlation	0.233	-0.518	0.384	0.319	-0.099	0.309
	Sig.(two-tailed)	0.615	0.234	0.395	0.485	0.832	0.500
FRU	Pearson correlation	0.365	0.154	-0.274	-0.224	-0.374	0.783*
	Sig.(two-tailed)	0.421	0.742	0.552	0.629	0.409	0.037
PLY	Pearson correlation	-0.134	-0.148	0.017	-0.033	0.150	0.187
	Sig.(two-tailed)	0.775	0.751	0.972	0.944	0.748	0.688
FLV	Pearson correlation	0.320	-0.420	0.417	0.436	0.497	0.387
	Sig.(two-tailed)	0.484	0.348	0.352	0.328	0.257	0.391

**: The correlation is significant at the 0.01 level (two-tailed). *: The correlation is significant at the 0.05 level (two-tailed). MC = Moisture content, TA = Titratable acidity, Conduc = Conductivity, GLU = Glucose, SUC = Sucrose, FRU = Fructose, PLY = Polyphenol, FLV = Flavonoid.

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However, it is important to note that the effects of ingesting polyphenols are dependent on the amount consumed and their bioavailability. Undesirable consequences for human health result from the ability of these substances to impede iron absorption, inhibit digestive enzymes, affect hormonal balance, and interact with pharmacological agents. Thus, despite the abundance of polyphenols in the raspberry samples studied, there is the need for caution in the consumption of these compounds in order to benefit from the inherent beneficial effects associated with these samples.[70]

Flavonoid content in the raspberry samples studied ranged from 111.20 mg to 261.80 mg per 100 g. Sample 4 also showed a higher flavonoid content than the other raspberry samples studied, while the raspberry sample 7 had the lowest flavonoid content. Raspberry samples 1 and 4 which are rich in sugars displayed a high content of flavonoid. Similarly, raspberry sample 7 which had low sugar content also displayed a low content of flavonoids. The flavonoid contents recorded in the present study are significantly higher than those obtained in previous study, where flavonoid contents of 20.31 - 47.14 mg/100 g was recorded for red raspberries,[71] and 52 - 121 mg/100 g for black raspberry.[72]

It has been established that flavonoids exert a variety of effects on various health conditions. Their positive impact on metabolic pathways associated with diabetes and gastrointestinal cancers has been demonstrated, acting in a targeted manner on altered pathways such as apoptosis and cell proliferation.[73] Additionally, it has been demonstrated that flavonoids possess the capacity to impede the metabolic process of midostaurin, a medicinal substance employed in the management of specific categories of cancers.[74]

Flavonoids have a wide range of beneficial effects on human health, including antioxidant, anticancer, antimicrobial, neuroprotective, and anti-inflammatory effects. Their mechanism of action involves promotion of enzyme and arachidonic acid secretion, modulation of cytokine expression, regulation of gene expression of pro-inflammatory molecules, and promotion of pro-inflammatory enzymes.[75] They also have potential as adjuvants in the treatment of cardiovascular pathologies, and it has anti-adipogenic effects.[76,77]

Findings from the present study have revealed higher content of flavonoids in raspberries compared to previous studies. Therefore, regular consumption of raspberry samples appears to have beneficial effects on human health, however, excessive consumption may result in undesirable effects, which may include induction of genotoxic/carcinogenic effects, interference with thyroid hormone biosynthesis, and estrogenic activity likely to influence sexual development in children.[78] In addition, flavonoids may impair nutrient absorption, interact with drug pharmacokinetics, and impact neurobehavioral development.[78]

Table 6b: Continuation of the Correlations among Moisture content, pH, Titratable Acidity, Conductivity, Mg, Ca, Cl, P, Glucose, Sucrose, Fructose, Polyphenols, and Flavonoids

		Cl	**P**	**GLU**	**SUC**	**FRU**	**PLY**	**FLV**
MC	Pearson correlation	0.337	0.709	0.318	0.233	0.365	-0.134	0.320
	Sig.(two-tailed)	0.460	0.075	0.486	0.615	0.421	0.775	0.484
pH	Pearson correlation	0.686	-0.624	-0.455	-0.518	0.154	-0.148	-0.420
	Sig.(two-tailed)	0.089	0.134	0.304	0.234	0.742	0.751	0.348
TA	Pearson correlation	-0.570	0.781*	0.402	0.384	-0.274	0.017	0.417
	Sig.(two-tailed)	0.181	0.038	0.371	0.395	0.552	0.972	0.352
Conduc	Pearson correlation	-0.423	0.838*	0.376	0.319	-0.224	-0.033	0.436
	Sig.(two-tailed)	0.344	0.019	0.406	0.485	0.629	0.944	0.328
Mg	Pearson correlation	-0.141	0.390	0.251	-0.099	-0.374	0.150	0.497
	Sig.(two-tailed)	0.763	0.388	0.587	0.832	0.409	0.748	0.257
Ca	Pearson correlation	0.528	0.217	0.437	0.309	0.783*	0.187	0.387
	Sig.(two-tailed)	0.223	0.640	0.327	0.500	0.037	0.688	0.391
Cl	Pearson correlation	1	-0.291	-0.528	-0.594	0.270	-0.254	-0.283
	Sig.(two-tailed)		0.527	0.223	0.159	0.558	0.583	0.538
P	Pearson correlation	-0.291	1	0.567	0.457	0.079	-0.221	0.389
	Sig.(two-tailed)	0.527		0.185	0.302	0.866	0.633	0.389
GLU	Pearson correlation	-0.528	0.567	1	0.928**	0.474	0.483	0.746
	Sig.(two-tailed)	0.223	0.185		0.003	0.283	0.272	0.054
SUC	Pearson correlation	-0.594	0.457	0.928**	1	0.557	0.386	0.533
	Sig.(two-tailed)	0.159	0.302	0.003		0.194	0.392	0.218
FRU	Pearson correlation	0.270	0.079	0.474	0.557	1	0.105	0.162
	Sig.(two-tailed)	0.558	0.866	0.283	0.194		0.823	0.729
PLY	Pearson correlation	-0.254	-0.221	0.483	0.386	0.105	1	0.787
	Sig.(two-tailed)	0.583	0.633	0.272	0.392	0.823		0.036
FLV	Pearson correlation	-0.283	0.389	0.746	0.533	0.162	0.787	1
	Sig.(two-tailed)	0.538	0.389	0.054	0.218	0.729	0.036	

**: The correlation is significant at the 0.01 level (two-tailed). *: The correlation is significant at the 0.05 level (two-tailed). MC = Moisture content, TA = Titratable acidity, Conduc = Conductivity, GLU = Glucose, SUC = Sucrose, FRU = Fructose, PLY = Polyphenol, FLV = Flavonoid.

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Flavonoids can have a complex impact on mutagenesis and carcinogenesis due to their potential to act as both antimutagens, and promutagens, as well as antioxidants and pro-oxidants, depending on consumption levels and physiological conditions.[79] Flavonoids have additionally demonstrated the capability to induce detrimental consequences on the gastrointestinal system, which include the development of gastric ulcers, diarrhea, and prolonged inflammation.[80] Factor such as the bioaccumulation of flavonoids or polyphenols from various sources, such as fruits, vegetables, and other foods, that may aggravate these pathologies should not be taken for granted.[81,82] For this reason, it is imperative to establish a recommended daily intake limit for flavonoids and polyphenols, to prevent overexposure to these molecules from a variety of food sources.

Outcomes of the correlation analysis among various parameters of raspberry samples

The results presented in Tables 6a and 6b highlight several correlations between physicochemical parameters, mineral content, sugars and antioxidant molecules. The analysis of Pearson's correlation between pH and citric acid reveals a significant correlation coefficient of -0.945, with a significance value of 0.001 (two-tailed) at 0.01 threshold. This strong negative correlation suggests an inverse relationship between pH and total acidity, indicating that as pH increases, total acidity tends to decrease, and vice versa.

The relationship between pH and conductivity reveals a high correlation coefficient of -0.889, which indicated a statistically significant association with a significance value of 0.007 (two-tailed) at the 0.01 threshold. This observed negative correlation implies a reciprocal connection between pH and conductivity, wherein an elevation in pH corresponds to a decline in conductivity, and vice versa.

The correlation between citric acid concentration and conductivity reveals an extremely high correlation coefficient of 0.982, with a significance value of 0.000 (two-tailed) at the 0.01 threshold. This strong positive correlation suggests a direct relationship between citric acid concentration and conductivity, indicating that as the citric acid concentration increases, conductivity tends to increase, and vice versa. On the basis of these results, one can conclude that citric acid may be the primary factor influencing the acidity and conductivity of the raspberry samples.

The Pearson correlation analysis between citric acid concentration and phosphorus concentration, as well as conductivity and phosphorus concentration, indicates a statistically significant correlation at the 0.05 threshold. This positive correlation suggests a direct relationship between citric acid concentration and phosphorus concentration, as well as between conductivity and phosphorus concentration: as phosphorus concentration increases, citric acid concentration and conductivity tend to increase, and vice versa.

The analysis of the correlation between fructose concentration and calcium concentration showed a correlation coefficient of 0.783. The significant value associated with this correlation, at a significance level of 0.037 (two-tailed), indicates a statistically significant correlation at the 0.05 threshold. This positive correlation suggests a direct relationship between fructose concentration and calcium concentration.

The analysis of the correlation between glucose concentration and sucrose concentration revealed an exceptionally high correlation coefficient of 0.928. The significant value associated with this correlation, at a significance level of 0.003 (two-tailed), indicates a statistically significant correlation at the 0.01 threshold. This strong positive correlation suggests a direct relationship between glucose concentration and sucrose concentration.

By establishing the correlations among the various parameters analyzed, we aim to provide an overview of the interrelationships among the raspberry samples. This approach enables us to draw meaningful connections between quality parameters, mineral composition, and bioactive compounds, offering a new understanding of the overall nutritional profile of raspberries.

Conclusion

The findings of the present study highlight the nutritional values of the examined raspberries, marked by elevated levels of chloride, phosphorus, polyphenols, and flavonoids, coupled with a moderate sweetness profile, contributing to their overall health benefits. Therefore, integrating raspberries into dietary practices will promote a balanced and healthy diet. The results of our study make it possible to classify the different samples of raspberries according to their nutritional qualities.

Further research will enable the study of the medicinal properties such as antioxidant, neuroprotective and anti-inflammatory properties associated with raspberry consumption.

Furthermore, the outcomes hold potential implications for raspberry cultivation, offering guidance to farmers in refining their practices to enhance nutrient and bioactive content in raspberries. Future studies might explore innovative agricultural techniques or breeding strategies to optimize raspberry nutritional profiles.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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