DOI: 10.17533/udea.vitae.v29n3a348980
Natural products

Evaluation of antioxidant activity, phenolic content, anthocyanins, and flavonoids of fresh and dried 'Biloxi' blueberries

Evaluación de la actividad antioxidante, contenido fenólico, antocianinas y flavonoides de arándanos 'Biloxi' frescos y secos

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Abstract
Background: The phytochemical content present in blueberries has generated great interest, especially in the nutra-pharmaceutical industry, where it is known as the "super fruit" due to its prevention and treatment of neurodegenerative diseases (cardiovascular diseases, diabetes, and cancer, among others).
Objectives: This study evaluated the functional potential of fresh blueberries and dried blueberries using forced convection by measuring phytochemical content to conclude if this drying technology is convenient for prolonging the product's shelf life.
Methods: For this purpose, antioxidant activity, phenolic content, total anthocyanins, and total flavonoids of 'Biloxi' blueberry cultivars were determined. Fresh and dried blueberries' results were studied. Fruit extracts were analyzed to determine antioxidant activity using 2,2-diphenyl-1-picrylhydrazyl (DPPH) as a free radical, total phenolic content with Folin-Ciocalteu reagent, total anthocyanins by pH differential method, and total flavonoids by Aluminum Chloride method.
Results: Results for fresh blueberries yielded ranges of antioxidant activity (90.8-93.9% Free radical scavenging rate), total phenolic content (275 to 645mgGAE/100gFW), total anthocyanins content (28.55 to 43.75mgCy3G/100gFW) and total flavonoids content (159.92 to 335.75mgQE/100gFW). For the forced convection oven process, ranges of antioxidant activity (85.5-92.6% Free radical scavenging rate), total phenolic content (261 to 308mgGAE/100gFW), total anthocyanins content (4.74 to 5.12mgCy3G/100gFW) and total flavonoids content (30.66±0.38mgQE/100gFW) were obtained.
Conclusions: In general, blueberries studied proved to have similar concentrations of functional properties compared to a wide variety of cultivars grown around the globe. Furthermore, higher concentrations of phytochemical content than those reported previously

for strawberries, blackberries, and raspberries were evidenced. Although dried blueberries studied proved to have diminished phytochemical content, this functional component content stands out among the fruits market and give nutritional value to end consumers. Drying processes could potentially increase the commerce of blueberries by significantly reducing their perishable nature.
Key words: Biloxi cultivar, southern highbush, forced convection, phytochemical content.

Resumen

Contexto: El contenido fitoquímico presente en los arándanos ha generado gran interés, especialmente en la industria nutra-farmacéutica donde es conocido como una "super fruta" debido a su ayuda en la prevención y tratamiento de enfermedades neurodegenerativas, enfermedades cardiovasculares, diabetes, cáncer, entre otras.

Objetivos: Este estudio evaluó el potencial funcional de arándanos frescos y deshidratados por convección forzada mediante la determinación de su contenido fitoquímico con el objetivo de concluir si esta tecnología de secado es conveniente para aumentar la vida útil del producto.

Métodos: Para este propósito, se determinó la actividad antioxidante, el contenido fenólico, las antocianinas totales y los flavonoides totales de cultivos de arándanos 'Biloxi' La información recopilada de la literatura fue analizada. Se estudió el contenido en compuestos funcionales en arándanos frescos y deshidratados. Los extractos de fruta fueron analizados para determinar actividad antioxidante por medio de 2,2-Difenil-1-Picrilhidrazilo (DPPH) como radical libre, fenólicos totales con el reactivo Folin-Ciocalteu, antocianinas totales usando el método diferencial de pH y flavonoides totales con el método de Cloruro de Aluminio.

Resultados: Para los arándanos frescos se obtuvieron rangos de actividad antioxidante de 90.8-93.9% Tasa de captación de radicales libres, contenido fenólico total de 275-645mgEAG/100gPF, contenido de antocianinas totales de 28.55-43.75mgCy3G/100gPF y contenido total de flavonoides de 159.92-335.75mgEQ/100gPF. Para los arándanos deshidratados por convección forzada, se obtuvieron rangos de actividad antioxidante de 85.5-92.6% Tasa de captación de radicales libres, contenido fenólico total de 261-308mgEAG/100gPF, contenido de antocianinas totales de 4.74-5.12mgCy3G/100gPF y contenido total de flavonoides de 30.24-30.96mgEQ/100gPF.

Conclusiones: En general, los arándanos estudiados probaron tener concentraciones similares de propiedades funcionales comparados con una amplia variedad de cultivos alrededor del mundo. Además, fueron evidenciadas concentraciones más altas de contenido fitoquímico comparadas con las reportadas previamente para fresas, moras y frambuesas. Aunque los arándanos secos estudiados demostraron tener menor contenido fitoquímico, la cantidad de estos componentes funcionales destaca dentro del mercado de las frutas y dan valor nutricional a los consumidores. Los procesos de secado pueden potencialmente incrementar el comercio de arándanos derivado de una disminución significativa en su naturaleza perecedera.

Palabras clave: Cultivo Biloxi, southern highbush, convección forzada, contenido fitoquímico.

Received: 25/02/2022

Accepted: 11/08/2022

Introduction

The blueberry belongs to the Ericaceae family, Vaccinium genus, with approximately 450 species worldwide, mainly distributed in the Northern Hemisphere(1). The cultivars that predominate in the industry include 'Misty', 'Duke', 'Bluecrop', 'Legacy', 'O´Neal', 'Brigitta', 'Elliot', 'Star', 'Emerald', 'Biloxi', and 'Sharpblue', among others(1,2,3). The United States Department of Agriculture-Agricultural Research Service (USDA-ARS) in Mississippi has developed several southern highbush types, including 'Biloxi'(1998), 'Lupton' and 'Magnolia'(1).

The proximate composition of blueberries is 83% water, 0.7% protein, 0.5% fat, 1.5% fiber, and 15.3% carbohydrate by weight (4). Blueberries have 3.5% cellulose and 0.7% soluble pectin. Total sugars account for more than 10% of the fresh weight, and the predominant reducing sugars are glucose and fructose, which represent 2.4%. The overall acid content of Vaccinium fruit is relatively high, with blueberries falling in the range of 1-2%. The primary organic acid in blueberries is citric acid (1.2%). They also contain significant amounts of ellagic acid; a compound thought to reduce the risk of cancer (5). Compared with other fruits and vegetables, blueberries have intermediate to low levels of vitamins, amino acids, and minerals (4), with 22.1 mg of vitamin C per 100 g of fresh weight; unusually, arginine is their most prominent amino acid. According to the Food and Agriculture Organization of the United Nations (FAO), in 2017, the global production of blueberries was 1.22 million tons, showing an increase of 53.9% from 2010 (6).

Among fresh fruits, blueberries are one of the richest sources of antioxidant phytonutrients, with total antioxidant capacity ranging from 13.9 to 45.9 μmol Trolox equivalents/g fresh berry(7,8,9). There is considerable variation among blueberry cultivars in antioxidant capacity, although its skin has the highest concentration of antioxidants and phenolics. Besides genotype, the antioxidant capacity can be affected by location, growing season, cultural management, maturity, and postharvest handling and storage(1).

Total anthocyanins in blueberries range from 85 to 270 mg per 100 g, although the relative proportions vary(10). The predominant anthocyanins were delphinidin-monogalactoside, cyanidin-monogalactoside, petunidin-monogalactoside, malvidin-monogalactoside and malvidin-monoarabinoside(1).

An array of phenolics is present in blueberry fruits, including anthocyanins, quercetin, kaempferol, myricetin, chlorogenic acid, and procyanidins, which contribute to antioxidant capacity. Anthocyanins account for up to 60% of the total phenolic content in highbush blueberries(11). Berries from the various Vaccinium species contain relatively high levels of polyphenolic compounds, with chlorogenic acid predominating(10).

There is strong evidence that the antioxidants in fruits and vegetables protect lipids, proteins, and nucleic acids against oxidative damage initiated by free radicals. It has been established that free radicals play a major role in cancer, heart, vascular, and neurodegenerative diseases(12). Blueberries had the highest antioxidant capacity value among 41 fruits and

vegetables tested using an assay for oxygen radical absorbing capacity (ORAC). Although various kinds of antioxidants have been identified in fruit, anthocyanins and other phenolic compounds have received the greatest attention[13]. These properties have generated significant interest, especially in the nutra-pharmaceutical industry, where it is known as the "super fruit" due to its prevention and treatment of neurodegenerative diseases, cardiovascular diseases, diabetes, and cancer, among others [13,14,15]

Although blueberries have proven to provide functional benefits to end consumers, their perishable nature is an important drawback in their commerce. Limited shelf life may restrain customers from purchasing this product[16]. As a result of this, a new challenge in the industry may arise. It is necessary to find a way to extend fresh fruits' shelf life that does not impair their functional benefits. An alternative to solve this issue may be dehydration. Experimental studies are required to conclude the potential use of this processing technique on a large scale,[17].

Colombia's Processed Fruit and Vegetable industry represented 285 billion COP in 2015 and increased to 405 billion COP in 2020[18]. Analyzing the industry by ingredients, fruits have represented about 2.2% of the processed fruit and vegetable industry in Colombia in the past 5 years (2015-2020). ranging from 1,817.8 to 1,887.7 tons per year. It may be concluded that dehydrated fruit products in Colombia must be developed and established in upcoming years. For this purpose, preliminary studies such as this research are needed.

Technologies such as the indirect hybrid solar-electrical forced convection dryer have been studied to process agri-foods[17]. Note that this equipment reduces electrical energy consumption compared to electric forced convection dryers and thus impacts the sustainability of the drying process. The study in question analyzed the drying effects on antioxidant activity, total flavonoid content, total phenolic content, energy consumption, and energy efficiency in apple peels processing[17]. It showed that antioxidant activity, total flavonoid content, and total phenolic content decrease at higher temperatures (> 70°C)[17]. In contrast, energy consumption decreases, and energy efficiency increases at higher processing temperatures (70-80°C)[17].

To our knowledge, information related to functional compounds in dried blueberries and their phytochemical content is scarce. Thus, this study evaluated the functional potential of fresh and dried blueberries using forced convection by measuring phytochemical content to conclude if this drying technology is convenient for prolonging the product's shelf life. For this purpose, antioxidant properties, phenolic content, anthocyanins, and flavonoids were determined.

Materials and Methods

Sample Preparation

'Biloxi' blueberries required for this study were cultivated in Villapinzón, Colombia. Freshly ripened (100% blue and fully ripe, based on surface color)[11] blueberries were harvested and

distributed within one day. Blueberries were washed with a 100-ppm sodium hypochlorite solution and rinsed with water to remove any residue. The fruit was stored at 4 °C for further analysis[19].

Dehydration process

A forced convection oven (Memmert® UNE 400 Drying oven; Germany) was used to dehydrate blueberries described in section 2.1. The convection oven drying procedure described by Hames [20] was followed. 100 g of fresh blueberries were placed evenly inside the equipment (Memmert® UNE 400 Drying oven; Germany) at 50 °C and 100% fan speed according to the manufacturer for 54 h. As evaluated previously by other authors, for complete dehydration, higher temperatures and longer times are required[17]. Initial and final moisture content was 83% wet basis (w.b.) and 5.63% w.b., respectively.

Fruit extraction

Fruit homogenate of fresh and convection oven processed blueberries was obtained by crushing about 10 g of 'Biloxi' blueberries in a mortar for about 1 min to minimize damage to the food matrix and preserve as much of the fruit's skin as the highest concentration of antioxidants and phenols in blueberries is found in the skin[1]. A homogeneous mixture was achieved. Fruit extract used for antioxidant activity, total phenolic content, total anthocyanins, and total flavonoids determinations were obtained by the sequential extraction procedure described by Giovanelli with some modifications[21]: 2.5 g of homogenate were weighed and added with 3.75 mL of industrial ethanol [80% v/v]. The mixture was stirred with a magnetic agitator (Barnstead, Thermo Fisher Scientific®, Cimarec top stirring hot plate; USA) for 1 h in the dark at 150 rpm and centrifuged (Thermo Fisher Scientific®, IEC CL40R centrifuge; USA) at 4,000 g for 10 min at 15 °C. The pellets were extracted two more times using 3.75 mL and 2.5 mL of the extraction solvent for 15 min under shaking in the dark and centrifuged in the above-described conditions. Finally, the gathered extracts were filtered (Munktell Filtrak® Grade 1003 General Purpose Filter Papers. Particle Retention: 12 to 15 μm; Germany) by gravity filtration and made up to 25 mL with the extraction solvent. Extractions were carried out in triplicate. Note that extracts used for antioxidant activity, total phenolic content, total anthocyanins, and total flavonoid determinations were each made fresh on a different day.

Phytochemical quantification

Extracts were analyzed to determine antioxidant activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay[22], total phenolic content with Folin-Ciocalteu reagent[23], total anthocyanins by pH differential method [24] and total flavonoids by Aluminum Chloride method[25].

Determination of Antioxidant Activity

The antioxidant activity was determined as a free radical using DPPH (Merck KGaA®, CAS: 1898-66-4; Germany). The free radical scavenging activity of blueberry extract (0.1-0.5 mL of fruit extract, 0.1 g/mL) was evaluated at 517 nm according to the literature protocol described by Wang and Gómez-Hernández with slight modifications[26,27]. Fruit extract, dissolved with methanol [99%] to 1 mL, was mixed with 2 mL of 0.2 mM DPPH in methanol, and the absorbance was measured (PG instruments® T80+ UV-Vis Spectrophotometer; UK) after 30 min incubation at 40 °C in the dark. The percentage of free radical scavenging rate was expressed as the percentage decrease in absorbance of the sample compared with the absorbance of the control using Equation 1.

Equation 1. Percentage of free radical scavenging rate.

$$(\%)Free\ radical\ scavenging\ rate = \frac{|(A_{control} - A_{sample})|}{A_{control}} x100\%$$

$A_{control}$ is the absorbance of the control reaction (1 mL of methanol [99%] and 2 mL of 0.2 mM DPPH).
A_{sample} is the absorbance of the mixture with the sample extract.

Determination of Total Phenolic Content

An adjusted method [23] with Folin-Ciocalteu reagent was used to determine the total phenolic content. The gallic acid standard solution had a concentration of 5 g per liter, with 0.25 g of gallic acid (Merck KGaA®, CAS: 149-91-7; Germany) and was added to 10 mL of industrial ethanol [96%] followed by dilution to 50 mL. The total phenolic content was measured as follows: In a 5 mL volumetric flask, 50 µL of diluted extract (0.1 g/mL) or standard solution of gallic acid were mixed with 3 mL of deionized water, then 0.25 mL of Folin-Ciocalteu reagent (PanReac AppliChem ITW Reagents®, code: A5084; Germany) were added to the mixture and stirred with a glass rod. After 5 min, 0.75 mL of (7% w/v) Sodium carbonate (PanReac AppliChem ITW Reagents®, CAS: 497-19-8; Germany) solution were added. The solution was immediately filled up to 5 mL with deionized water. After incubation at 40 °C for 30 min in a thermostatic bath, the absorbance of the solution was measured by the spectrophotometer (PG instruments® T80+ UV-Vis Spectrophotometer; UK) at 765 nm. The results were calculated according to the calibration curve for gallic acid (y=0.0005x-0.004,

y=absorbance at 765 nm, x=concentration of gallic acid in mg/L, R2=0.9689) that ranged from 0.1-0.6 mg/mL. The content of total phenolic content was expressed as mg of gallic acid equivalents (GAE) per 100 g Fresh Weight (FW)[28].

Determination of Total Anthocyanins

The total anthocyanin content of diluted fruit extract was estimated by the pH differential method[29] used by other authors previously[30,31,32,33]. A potassium chloride buffer (0.025 M, pH 1.0) was prepared by mixing 0.1 g KCl (PanReac AppliChem ITW Reagents®, CAS: 7447-40-7; Germany) and 50 mL of deionized water in a beaker with a glass rod. pH (Mettler Toledo®, S47 SevenMulti dual meter pH/conductivity; USA) was measured and adjusted to 1.0 with approximately 1 mL of HCl [18%]. To prepare the sodium acetate buffer (0.4 M, pH 4.5), 2.72 g Sodium Acetate 3-hydrate (PanReac AppliChem ITW Reagents®, CAS: 6131-90-4; Germany) and 50 mL of deionized water were mixed in a beaker with a glass rod. The pH was measured and adjusted to 4.5 with approximately 3.1 mL of HCl [18%]. Fruit extract was diluted with potassium chloride buffer, pH 1.0 until the absorbance of the sample at 510 nm was within the linear range of the spectrophotometer (PG instruments® T80+ UV-Vis Spectrophotometer; UK) to determine the appropriate dilution factor for the sample. The dilution factor was obtained by dividing the final volume of the sample by the initial volume. The dilution factor was 10. Deionized water was used to zero the spectrophotometer at 510 nm and 700 nm. The extract dilutions were prepared twice: once with potassium chloride buffer (pH 1.0) and then with sodium acetate buffer (pH 4.5). The dilutions were allowed to equilibrate for 15 min before their absorbances were measured in the spectrophotometer. Absorbance (A) was measured at 510 nm and 700 nm in both buffers respectively. Samples were evaluated in triplicate. The following Equation 2 and Equation 3 were applied to estimate the total anthocyanin content:

Equation 2. Absorbance of the diluted sample.

$$A = (A_{510} - A_{700})_{pH1.0} - (A_{510} - A_{700})_{pH4.5}$$

Equation 3. Anthocyanin concentration.

$$TAC(mg/L) = \frac{(A * MW * DF * 1000)}{(\varepsilon * 1)}$$

Where DF is the dilution factor, MW is the molecular weight of cyanidin-3-O-glucoside (Cy3G) (MW = 449.2 g/mol), and ε its molar absorptivity (26,900 $\frac{L}{cm*mol}$). Total anthocyanin content was expressed as mg Cy3G per 100 g of FW[34,35,36,37].

Determination of Total Flavonoids

The total amount of flavonoids were measured using the aluminum chloride ($AlCl_3$) method at 510 nm as reported previously by Dragović-Uzelac [23] with minor modifications. 1 mL of the sample (0.1 g/mL) or standard solution was added to a 10 mL volumetric flask. The extract was mixed with 4 mL of deionized water and 0.3 mL of (5% w/v) sodium nitrate (PanReac AppliChem ITW Reagents®, CAS: 7631-99-4; Germany) solution. After 5 min, 0.3 mL of (10% w/v) Aluminum chloride 6-hydrate (PanReac AppliChem ITW Reagents®, CAS: 7784-13-6; Germany) solution was added. After another 6 min, 2 mL of 1 M sodium hydroxide (Merck KGaA®, CAS: 1310-73-2; Germany) solution was added. The volume was filled up to 10 mL with deionized water. The mixture was allowed to stand at room temperature for 60 min in the dark. Then the absorbance was measured (PG instruments® T80+ UV-Vis Spectrophotometer; UK) against deionized water blank at 510 nm wavelength. The calibration curve ranged from 35-100 µg/mL [26,27] (y=0.0012x-0.0339, y=absorbance at 510 nm, x=concentration of quercetin in µg/mL, R2=0.9973). The standard solution had a concentration of 1 mg per mL, with 0.1 g of quercetin dihydrate (quercetin dihydrate [97%]: Alfa Aesar®, CAS: 6151-25-3; USA) being added to 100 mL of deionized water. Total flavonoids were expressed in mg Quercetin Equivalent (QE) per 100 g FW[19,37,38].

Results

Dehydration Process

Processing ‘Biloxi’ blueberries through the forced convection oven (54 h, 50 °C) yielded an efficiency of 94.4%. Initial and final moisture content was 83% w.b. and 5.63% w.b., respectively. Figure 1 shows the fresh product on the left and blueberries after the dehydration process on the right.

Figure 1. Fresh blueberries (left), dried blueberries by forced air convection process (right).

Phytochemical quantification

Table 1 summarizes results obtained by experimentation of antioxidant activity, total phenolic content, total anthocyanins, and total flavonoids of fresh and dried 'Biloxi' blueberries. Data reported by previous authors on highbush blueberries are also shown.

Table 1. Antioxidant Activity, Total Phenolic Content, Total Anthocyanins, and Total Flavonoids of fresh and dried 'Biloxi' blueberries. Other authors previously reported phytochemical content in highbush blueberries.

	Fresh blueberries		*Dried blueberries*		*Literature*		*Units*
	Range	Mean & deviation	Range	Mean & deviation	Range	References	
Antioxidant activity	90.8-93.9	92.56±1.31	85.5-92.6	88.4±3.01	76-84.9	(34)	Free radical scavenging %
Total phenolic content	275-645	425±164.77	261-308	287±21	170.9-434	(39)	mgGAE/100gFW
Total anthocyanins	28.55-43.75	32.31±5.71	4.74-5.12	4.93±0.27	120-382	(9)	mgCy3G/100gFW
Total flavonoids	159.92-335.75	229.27±50.53	30.24-30.96	30.66±0.38	30.44-87.55	(37)	mgQE/100gFW

Determination of Antioxidant Activity

The free radical scavenging rate according to Equation 1 for fresh blueberries ranged from 90.8-93.9%. In the case of dried blueberries by the forced convection processing, the free radical scavenging rate was 85.5-92.6%, as shown in Table 1 .

Determination of Total Phenolic Content

The total phenolic content for the extracts of fresh blueberries ranged from 275 to 645 mg GAE/100 g FW; the mean and deviation are 425±164.77 mg GAE/100 g FW. The total

phenolic content for the extracts obtained with dried blueberries by forced convection oven ranged from 261 to 308 mg GAE/100 g FW. The mean and deviation were 287±21 mg GAE/100 g FW.

Determination of Total Anthocyanins

Total anthocyanins determined by the pH differential method for the extracts obtained with dried blueberries by forced convection oven ranged from 4.74 to 5.12 mg Cy3G/100 g FW. The mean and deviation were 4.93±0.27 mg Cy3G/100 g FW. On the other hand, data for total anthocyanins for fresh blueberries was 28.55 to 43.75 mg Cy3G/100 g FW with a mean and deviation of 32.31±5.71 mg Cy3G/100 g FW.

Determination of Total Flavonoids

The range for total flavonoid content for the extracts obtained with dried blueberries by forced convection oven was 30.24 to 30.96 mg QE/100 g FW with a mean and deviation of 30.66±0.38 mg QE/100 g FW. On the other side, the range obtained for fresh blueberries was 159.92 to 335.75 mg QE/100 g FW with a mean and deviation of 229.27±50.53 mg QE/100 g FW.

Discussion

Dehydration Process

Forced air convection processing showed to be limited by the long time it takes to dry one batch of blueberries and the economic repercussion of 54 h of continuous heating and forced air circulation. Dried products should have longer shelf life due to the water content remotion(40). A visual representation of the product obtained is shown in Figure 1.

Phytochemical quantification

Besides genotype, the antioxidant capacity can be affected by location, growing season, cultural management, maturity, postharvest handling, and storage(1). Due to this variability

in antioxidant capacity, results were presented as a range of the corresponding phytochemical compounds in Table 1. It must be noted that 'Biloxi' is a southern highbush cultivar that was developed in Mississippi, United States, in 1998. This cultivar is widely grown in Mexico and Australia[1]. However, few studies of these regions that included 'Biloxi' cultivars regarding phytochemical quantification were found. Additionally, there were no found studies of phytochemical quantification of blueberries in Colombia. The present study should be considered a preliminary study on this matter, and new studies that support the evidence provided in this article are necessary.

Determination of Antioxidant Activity

Antioxidant activity results for blueberries processed through a forced convection oven were lower than those obtained for fresh blueberries but of the same order of magnitude (Table 1); which indicates that forced convection drying could be an alternative to prolong the shelf life of the product without affecting its antioxidant activity. Results obtained were according to those obtained previously in several studies, in fresh blueberries from highbush cultivars (76-84.9%), fresh raspberries (86.8-91.8%), and strawberries (80.9%)[34].

Determination of Total Phenolic Content

The range obtained for fresh blueberries was within the reported data in the literature (170.9-434 mg GAE/100 g FW) in thirty-nine blueberries cultivars[39]. It is shown that the total phenolic content in blueberries dried by forced convection oven processing was lower than the content reported for extracts obtained by processing fresh blueberries. However, it was higher (Table 1) than those reported by other authors for fresh highbush blueberries cultivars (39), blackberries, red raspberries, and strawberries[31]. Therefore, forced convection drying could be an option to prolong the product's shelf life while preserving a high total phenolic content.

Results show that the deviation of results was lower in the dried product than in the fresh one. This may be attributed to the fact that the ratio of skin to the product's total weight rises when the water is removed. The above leads to a higher probability of all samples having skin pieces, which have the highest concentration of antioxidants and phenols in blueberries with more than double phenols than those of the seeds[1], affecting the results. Within a batch of blueberries, some may be slightly more mature than others, affecting the phenolic content [11] and interfering with variability in results.

Determination of Total Anthocyanins

Results show that the total anthocyanin content reported in this study for fresh and dried blueberries were lower than those found for highbush blueberry, blackberry, black raspberry, red raspberry, and strawberry cultivars by other authors[8,31]. The variation found among the results of total anthocyanins could be related to many factors such as genotype, growing season, maturity, postharvest handling, and storage. Phytochemical content is known to change with the maturity of the fruit, and as the berry ripens, anthocyanin content increases[35]. The difference in the maturity state of the different blueberries evaluated in this study could explain the variability of the results obtained as well as the difference with those reported in the literature.

Determination of Total Flavonoids

The results of the total flavonoid content of fresh blueberries showed higher values compared to the results previously reported by other authors (Table 1), where a range between 30.44 and 87.55 mg QE/100 g FW was obtained when studying thirty varieties of highbush blueberries cultivars[37]. Fresh and dried blueberries studies produced ranges of total flavonoids that are within the range reported previously by other authors [19,37,38,41] in highbush blueberries cultivars but higher than those reported for strawberries (14.31±0.13 μg QE/g), blackberries (30.12±0.13 μg QE/g) and raspberries (22.98 ± 0.07 μg QE/g)[19]. Considering the total flavonoid content obtained for dried blueberries, forced convection drying could be an alternative to prolong the shelf life of the product while preserving its total flavonoids content and for consumers that are not able to purchase the fresh product.

Conclusions

Fresh 'Biloxi' blueberries yielded similar overall concentrations of phenolic content, total anthocyanin content, and total flavonoid content, compared to a wide variety of cultivars grown around the globe. This may suggest that the methods used in this study are trustworthy in measuring the phytochemical content of blueberries. Dried blueberries had concentrations of evaluated bioactive compounds of interest to consumers. Reducing the fruit's water content can extend the product's shelf life, so this processing should be recommended for consumers who cannot buy fresh fruit. Although the impact of processing blueberries through forced convection technology needs to be analyzed by further studies, the present article should be considered a preliminary study on this matter. There is a lack of studies on the phytochemical quantification of blueberries in Colombia. New studies on blueberry dehydration that support the evidence provided in this article are necessary, especially regarding antioxidant activity and total anthocyanin content. Variability in the data obtained and results observed in literature may be attributed to factors such as genotype, growing season, maturity, postharvest handling, and storage. Additionally, the concentration of phytochemical

compounds in blueberries varies in the skin, pulp and seeds. For this reason, studies that evaluate each part of the fruit on its own may allow a clearer perspective on the matter. This study provides further evidence that supports the functional potential of blueberries, especially in the nutra-pharmaceutical industry, where it is known as the "super fruit" due to its prevention and treatment of neurodegenerative and cardiovascular diseases, diabetes, and cancer, among others.

Conflicts of interest

The authors declare no conflict of interest.

Authors' contributions

Santiago Caicedo Narváez: Investigation; Experimentation, Writing- review & editing original draft. María Hernández Carrión: Project administration; Resources, Supervision, Writing- review & editing.

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