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Nutraceutical and nutritional characteristics of capulin segregants (*Prunus serotina*) fresh and processed

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Abstract

The capulin fruit (*Prunus serotina*; Family *Rosacea*) has been valued since pre-hispanic times for its medicinal properties, used in the treatment of some diseases. Although Mexico is part of the center of origin of the capulin, production and consumption of this fruit have decreased in recent years, becoming an underutilized fruit. There is little research on its nutritional and nutraceutical properties. The aim of this investigation was to evaluate the physicochemical properties, nutritional and nutraceuticals components of fresh and processed capulin fruits, from four segregants. Polar and equatorial diameter, peel color was determined by evaluating *L* (brightness), the angle of tone (*hue*) and color purity or *chromaticity* index (*chroma*), pH, and TSS; as well as the content of carbohydrates, ash, humidity, crude fiber, protein, and lipid content were quantified according to the AOAC guidelines. Mineral content was quantified by atomic emission spectrophotometry, phenolic compounds by the Folin-Ciocalteu method, anthocyanins by the pH differential method, and antioxidant activity by the ABTS method. The fruits showed high protein and fiber contents. Significant differences in nutraceutical content were found among the four types of segregants. The thermal process did not decrease the nutraceutical quality (except anthocyanins) of the four types of segregants, this only affected the nutritional attributes. Therefore, the segregants with the highest nutraceutical value were Puebla 5-28F and Puebla 5-3F, due to their high contents of phenolic compounds and anthocyanins. In conclusion, capulin fruits contain a wide variety of antioxidant and nutritional compounds, and their consumption could generate benefits for human health.

► **Keywords:** antioxidants, minerals, proximal, genetic segregation.

Introduction

Recently, in Mexico there has been a growing interest in the knowledge and management of underutilized fruit, also known as minor, secondary or alternative fruits, as it is the case of the capulin (*Prunus serotina*). Capulin belongs to the family *Rosaceae* and to the gender *Prunus*, where more than 200 species of commercially important species are found, such as cherry, peach, plum, among others, known as stone fruits (Potter, 2011). In 1951, McVaugh described five subspecies of *Prunus serotina*, the subspecies *capuli*, *serotina* and *virens*, coexist in several states of Mexico (Guzmán et al., 2020).

Prunus serotina is a deciduous tree native to America which grows in diverse regions in the wild or cultivated conditions, in cool semi-cold, humid and temperate climates. Its distribution includes southeastern Canada, northeastern United States, Ecuador, Colombia, Guatemala and the Sierra Madre Oriental, Occidental and the Neovolcanic axis of Mexico, (López-Hernández et al., 2024; Pathania et al., 2022). Currently, this species is naturalized in several countries around the world, including in various regions of Europe (Germany, Denmark, France, England, Lithuania, the Netherlands, Poland, Romania, Switzerland, among others) (Petitpierre et al., 2009). In the United States,

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capulin is known as wild or black cherry, in Europe as Mexican cherry (Petitpierre et al., 2009). In 2023, Mexico reported formal cultivation of capulin only in Veracruz, Mexico City, Puebla, Estado de Mexico and Jalisco, with a harvested area of 37 ha with a production of 114.28 t of this fruit (SIAP, 2024).

Capulin fruits are globose fleshy drupes, reddish to black in color depending on their state of ripeness, climacteric in nature and sweet and sour in taste; they also commonly contain cyanogenic glycosides (prunazine and amygdalin), excessive consumption, without thermal processing, can have adverse health effects (Telichowska et al., 2020). According to Swain et al. (1992), the presence of cyanogenic glycosides in some members of the genus *Prunus* is considered a defense mechanism of the plant against herbivores and pathogens through the release of hydrogen cyanide (HCN) and benzaldehyde. In the particular case of *P. serotina*, it is reported to accumulate high levels of cyanogenic glycosides in the ripe fruit; However, it lacks the enzymes amygdalin hydrolase (AH), prunasin hydrolase (PH) and mandelonitrile lyase (MDL) that by hydrolysis would release HCN, so these only contribute to the bitter taste that is compensated by the accumulation of sugars at maturity of consumption, in contrast, the seeds during the roasting process are destroyed by the temperature of the cyanogenic glycosides (Telichowska et al., 2020).

In general, the fruits of *P. serotina* are marketed fresh, dried, or in jams, liqueurs or syrups; the seeds are eaten roasted with salt as a snack (Ordaz-Galindo et al., 1999). Since pre-Hispanic times, its fruits have been traditionally used for the treatment of some diseases (respiratory, cardiac, stomach and hypertension) (García-Aguilar et al., 2015; Luna-Vázquez et al., 2013). In addition, the capulin fruit has attracted attention as a potential source of nutrients and antioxidants. Ordaz-Galindo et al. (1999) reported the presence of anthocyanins (cyanidin-3-glucoside and cyanidin-3-rutoides) in the peel of *P. serotina* subsp. *capuli*. Moreover, Ibarra-Alvarado et al. (2009) point out the presence of antihypertensive compounds such as some phenolic ones (acid chlorogenic) in the fruit, metabolites that could justify its medicinal properties. Hernández Rodríguez et al. (2019) report that the content of flavonoids and phenolic compounds decreases in the last stages of fruit ripening, with a considerable increase of total anthocyanins of up to 1.4 mg cyanidina-3-glucósido · g⁻¹ dry weight. The high content of phenolic compounds (phenolic acids), flavonoids (anthocyanins, proanthocyanidins, catechins), essential oils and tannins (Jiménez et al.; 2011.; Luna-Vázquez et al., 2013) explain its use as a natural therapy for the treatment of neurodegenerative diseases, such as some types of cancer, immune system problems and cardiovascular diseases (Poti et al., 2019; Telichowska et al., 2020)). In addition, capulin seed is a significant source of minerals, unsaturated fatty acids (oleic, linoleic and α -eleostearic acid) and high-quality, highly bioavailable proteins (García-Aguilar et al., 2015).

On the other hand, genetic studies of *P. serotina* have reported the phenomenon of allopolyploidy (union of genomes from different species), so intraspecific hybrids of capulin in Mexico with characteristics of different subspecies are available (Fresnedo-Ramírez et al., 2011; Pairon & Jacquemart, 2005). In addition, the morphological variability of the capulin in central-western Mexico is a product of human selection, directed at anthropocentric characters of interest, so that fruits of several sizes, degree of sweetness, with epicarp from reddish to almost black colorations, are found in wild populations, in *in situ* managed and cultivated (Fresnedo-Ramírez et al., 2011; Guzmán et al., 2020).

In this context, the morphological variability of the capulin is useful for the genetic improvement of this species, aimed at obtaining selections with better fruit and seed quality, or nutritional and nutraceutical value. In this sense, the Colegio de Postgraduados has a capulin collection with several segregant lots derived from outstanding individuals from the state of Puebla, mainly for their physicochemical characteristics. The term segregant used in this research denominates to individuals that were born by growing seeds from the same tree (sexual reproduction). Therefore, the objective of this study was to evaluate the physicochemical characteristics, content of nutraceutical compounds, antioxidant capacity and nutritional composition in the fruits of four fresh and processed capulin segregants.

Materials and Methods

Plant Material

Fruits were collected at commercial maturity stage from four segregants (individuals born from different seeds of the same tree) of capulin (*Prunus serotina*) grown in the Fruit Orchard of the Colegio de Postgraduados, Campus Montecillos, municipality of Texcoco, Estado de México, México (19°27' N, 98°54' O, 2 245 msnm): Puebla 5-1 (P5-1F), Puebla 5-3 (P5-3F), Puebla 5-18 (P5-18F) y Puebla 5-28 (P5-28F). The four segregants were selected because they are offshoots of the same tree, under the same edaphoclimatic conditions.

Experimental Design

The physicochemical characterization of the fruits of four capulin segregants was carried out under a completely randomized experimental design with 25 replications, the experimental unit consisted of one fresh fruit with seed. The mineral content in the pulp of fresh fruits of four capulin segregants was carried out under a completely randomized design with three replications, considering 100 g of fruits with peel and without seeds of each fresh segregant as the experimental unit. The effect of thermal treatment on the proximal and nutraceutical characteristics of capulin fruits was evaluated using an asymmetric

factorial experimental design with completely randomized allocation for the study of the factors: capulin segregant (four segregants) and degree of processing (fresh and processed). A total of eight treatments were evaluated with three replications. The experimental unit was 100 g of capulin fruits with peel and seedless of each segregant, fresh or processed (Table 1).

Statistical analysis

The data were submitted to an analysis of variance (ANOVA) and Tukey's mean comparison test ($P < 0.05$), using the Statistical Analysis System program (SAS Institute Inc., 2002). The results of the evaluated variables were expressed as the mean standard deviation.

Sample preparation

For processing, the fruit in water was kept at 40 °C by 5 min in an electric grill (Corning, model PC-620D, USA). The processed and fresh fruits were frozen with liquid nitrogen and stored to -18 °C, until analyzed.

Physical-chemical characterization

Polar and equatorial diameters of 25 fresh fruits with peel and seed of each segregant were measured using an electronic caliper (Truper, model CALDI-6MP, Jilotepec, Mexico). Fruit weight was determined on an analytic balance (Adventurer Pro AV64C, Ohaus Corporation, New Jersey, USA). Similarly, these variables were measured in the pulp-free capulin seed.

Peel color of fruit from each segregant was determined by evaluating *L* (brightness), hue angle tone (*hue*) and color purity or chromaticity (*chroma*) with a digital colorimeter (Chroma Meter CR-400, model B8210363, Konica Minolta Sensing, Inc., Tokyo, Japan) as described by McGuire (1992).

Total Soluble Solids (TSS) were determined using a refractometer (Hand-Held Refractometer, N-1E, ATAGO,

Tokyo, Japan) and pH using a potentiometer (HI2211 pH/ORP Meter, Hanna Instruments, Woonsocket, RI, USA) as established by the AOAC (2005).

Quantification of minerals

Peeled and seedless capulin fruit from each segregant were dehydrated in a forced convection air oven (Binder®, model KB115 Tuttlingen, Germany) to 60 °C by 48 h. The dried and milled samples were subjected to di acid wet digestion diácida ($H_2SO_4:HClO_4$, 4:1 v/v and H_2O_2) in a Digestor™ (Tecator Kjeltéc FOSS, model DT 220, Hoega-naes, Sweden). The determination of B, Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn was performed according to the methodology described by Alcántar-González & Sandoval-Villa (1999) in an Induction Coupled Plasma – Atomic Emission Plasma Spectrophotometer (ICP-AES, Instrument Varian Liberty series II, Sydney, Australia).

Proximal analysis

Carbohydrate, ash, humidity, crude fiber, protein and lipid contents were determined according to AOAC (2005). The results were expressed as percentage of fresh weight.

Quantification of nutraceuticals

Preparation of methanolic extract. To 1g of fruit pulp with peel from each segregant (fresh and processed) was added 10 mL of aqueous MeOH to 80 % (v/v), the mixture was homogenized by shaking in a vortex (Barnstead International, model M16715, Iowa, USA). Subsequently, it was sonicated (Cole Parmer 8892, Illinois, USA) for 15 min at environment temperature and allowed to settle for 24 h. Finally, it was centrifuged (Cole-Parmer Instrument Company, model 8892, Vernon Hills, IL, USA) at 1 409 g (10 min) for nutraceutical quantification (Román-Cortés et al., 2018).

Determination of phenolic compounds. 0.5 mL of the methanolic extract was taken and 0.5 mL of Folin-Ciocalteu reagent (0.2N) and 4 mL of 0.7 M of Na_2CO_3 , were added,

Table 1. Physical attribute of fruits and seeds of four segregants of capulin (*Prunus serotina*).

Variable	Segregant			
	P5-1F	P5-3F	P5-18F	P5-28F
	<i>Fresh fruit with seed</i>			
Weight (g)	3.04 ± 0.53 b	3.39 ± 0.32 a	2.18 ± 0.28 d	2.73 ± 0.26 c
Equatorial diameter (mm)	17.58 ± 1.27 b	18.83 ± 0.78 a	16.51 ± 0.86 c	16.74 ± 0.57 c
Polar diameter (mm)	15.69 ± 0.78 b	16.29 ± 0.45 a	14.76 ± 0.60 c	15.07 ± 0.52 c
	<i>Seed</i>			
Weight (g)	0.38 ± 0.03 b	0.51 ± 0.06 a	0.32 ± 0.02 c	0.38 ± 0.02 b
Equatorial diameter (mm)	9.57 ± 0.26 b	10.72 ± 0.29 a	9.09 ± 0.28 c	9.48 ± 0.26 b
Polar diameter (mm)	10.84 ± 0.40 c	12.38 ± 0.45 a	10.08 ± 0.32 d	11.77 ± 0.38 b

Values represent the average of 25 replicates ± standard deviation. Means with the same letter, in the same row, are statistically equal (Tukey, 0.05).

the mixture was incubated at environment temperature in darkness by 2 h. Readings were taken on a UV/Vis spectrophotometer (Thermoscientific, Genesys 10s, Florida, USA) at 765 nm. Concentration was calculated from a standard curve ($y = 0.0068x - 0.0003$; $R^2 = 0.995$) based gallic acid (Waterman & Mole, 1994). Total phenolic content was expressed as mg gallic acid equivalents per 100 g of fresh weight (mg EAG · 100 g⁻¹ p.f.).

Quantification of flavonoids. It was carried out following the method reported by Chang et al. (2002). To 0.5 mL of methanolic extract was added 1.5 mL of methanol (95 %), 0.1 mL de AlCl₃ (10 % p/v), 0.1 mL 1 M de CH₃COOK y 2.8 mL of distilled water. The mixture was homogenized and incubated for 30 min to environment temperature in darkness. The absorbance was read at 415 nm in a UV/Vis spectrophotometer. The standard curve ($y = 0.007x - 0.0051$; $R^2 = 0.999$) was constructed based on quercetin. Results were expressed as mg quercetin equivalents in 100 g fresh weight (mg EQ · 100 g⁻¹ p.f.).

Quantification of anthocyanins. It was carried out by means of the differential pH method described by Giusti & Wrolstad (2001). Two 0.2 mL samples methanolic extract were taken; to the first one 1.8 mL of a buffer solution pH = 1.0 (KCl) was added to the second one a buffer solution pH = 4.5 (CH₃COOH/CH₃COONa · 3H₂O) was added. Both samples were measured for absorbance at 510 and 700 nm. The total absorbance (A_T) was calculated from the formula: $A_T = [(A_{510} - A_{700})_{pH=1.0}] - [(A_{510} - A_{700})_{pH=4.5}]$. The anthocyanin concentration was calculated by the equation: $\text{Anthocyanins}(\text{mg} \cdot \text{L}^{-1}) = (A_T \cdot \text{PM} \cdot \text{FD} \cdot 1000) / (\epsilon \cdot 1)$; where: A_T=total absorbance, P.M = molecular weight (449.2 g · mol⁻¹) of cyanidin-3-glucoside, FD = dilution factor (10), ϵ = molar absorptivity of the standard (26 900). Concentration was expressed as mg cyanidin-3-glucoside per 100 g fresh weight of capulin.

Quantification of vitamin C (ascorbic acid). It was determined in pulp with peel of fresh and processed fruits of the four segregants, following the methodology described by Dürüst et al. (1997). For the preparation of the extract, 1 g of plant material was placed in 10 mL of 0.4 % (p/v) oxalic acid. The mixture was sonicated for 15 min at environment temperature, then filtered. One mL of the extract was mixed with 1 mL of acetate buffer pH = 3 (3 g anhydrous sodium acetate in 7 mL water and 10 mL glacial acetic acid) and 8 mL dichloroindophenol (from a 12 mg · L⁻¹ aqueous solution), after 15 s, absorbance was measured at 520 nm in a spectrophotometer. Results were expressed as mg ascorbic acid per 100 g of fresh weight (mg EAA · 100⁻¹ p.f.), using an ascorbic acid standard curve ($y = 0.004x + 0.0011$; $R^2 = 0.997$).

Evaluation of antioxidant capacity. To 10 mL solution of the ABTS radical ^{•+}(acid 2,2'-azinobis (3-ethylbenzothiazolin)-6-sulfonic acid), 6.61 mg of K₂S₂O₄ was

added, the mixture was allowed to stand at environment temperature in darkness for 16 h (Re et al., 1999). 1 mL of the ABTS radical was taken and absolute ethanol was added until an absorbance of 0.7 ± 0.01 a was obtained at a wavelength of 734 nm. To 1 mL of the ABTS radical, 10 µL of the extract to be analyzed was added and the mixture was incubated at 30 °C in darkness for 7 min. Finally, absorbance reading at 734 nm was taken. A standard curve ($y = -0.2895x + 0.7583$; $R^2 = 0.9956$) was prepared based on trolox. The results were expressed in mg equivalents of trolox per 100 g of fresh weight (mg ET · 100 g⁻¹ p.f.). To calculate the percentage inhibition of the free radical ABTS ^{•+} the formula was used: % inhibition = $[(A_0 - A_F) / A_0] \cdot 100$, where: A₀ = initial absorbance of the free radical at 734 nm, A_F = final absorbance of the reaction with the sample.

Results and Discussion

Physical-chemical properties

Significant differences ($P \leq 0.05$) were found between the physicochemical characteristics of the fruits of the four segregants. The P5-3F segregant presented significantly higher fruit weight and size, the smallest and lightest fruits were found in the P5-18F segregant. The same trend was found for seed weight and size (Table 1). Information on the morphological characteristics of the Mexican capulin fruit is limited; however, Hernández Rodríguez et al. (2019) report lower values of weight, polar and equatorial diameters (< 2.8 g, 1.1 cm y 1.2 cm, respectively) of fruits at consumption maturity of *P. Serotina* collected in Zacatlán, Puebla, Mexico, the differences are probably due to their wild nature.

Fruits of segregant P5-1F obtained the highest significant values of total soluble solids (TSS °Brix) and pH, therefore, they were the fruits with the lowest sourness and probably the sweetest. Fruits of segregants P5-3F, P5-18F and P5-28F showed no significant differences in TSS content, while fruits of the segregant P5-3 obtained the lowest pH and TSS values (Table 2). According to Baxter et al. (2005), the increased sucrose discharged from the phloem is the main factor causing differences in soluble solids content (TSS) among fruits of several plants of the same species. This could explain the higher TSS content in the P5-1F segregant. On the other hand, the pH values obtained in this research were higher than those reported by Ordaz-Galindo et al. (1999) (pH 3.96) and Jiménez et al. (2011) (pH 4.20) in fresh pulp of the same species (*Prunus serotina* subsp *capuli*), this could be due to genetic variability (Ballistreri et al., 2013).

Significant differences ($P \leq 0.05$) were found in the color parameters (*hue* angle of tone, *chroma* and brightness) of the fruit peel (Table 2). Fruits of segregant P5-1F showed the significantly higher values of *chroma* and *hue* angle

of tone (17.16 and 28.35, respectively), which identified them as fruits with higher intensity of orange. Fruits of segregant P5-28F showed the statistically lowest values of *chroma* and *hue* (6.18 and 20.95, respectively), which identified them as redder and lower color intensity fruits. Brightness values allowed dividing the fruits of the four segregants into two groups, the significantly lighter fruits (P5-1F and P5-3F) and the darker fruits (P5-18F and P5-28F). Peel color is the most important attribute of quality and maturity in capulin fruits, associated with the presence of anthocyanins (Hernández Rodríguez et al., 2019; Jimenez et al., 2011).

Mineral content

Significant differences ($P \leq 0.05$) in mineral content were observed among the fresh fruits of the four segregants (Table 4). Segregant P5-1F presented the statistically higher concentration of P, K and Mg, in contrast, fruits of segregant P5-28F showed significantly higher Na, Ca, Fe and Cu contents; segregants P5-1F, P5-28F and P5-3F obtained the highest B contents (Table 3). Luna-Vázquez et al. (2013) reported higher values of K ($184.30 \pm 3.50 \text{ mg} \cdot 100 \text{ g}^{-1} \text{ p.f.}$) and Na ($22.40 \text{ mg} \cdot 100 \text{ g}^{-1} \text{ p.f.}$) in capulin fruits harvested in Huejotzingo, Puebla, Mexico; as well as, lower contents of P ($28.10 \pm 0.40 \text{ mg} \cdot 100 \text{ g}^{-1} \text{ p.f.}$) and Ca ($12.90 \pm$

$1.90 \text{ mg} \cdot 100 \text{ g}^{-1} \text{ p.f.}$); however, the Mg content ($21.20 \pm 0.40 \text{ mg} \cdot 100 \text{ g}^{-1} \text{ p.f.}$) was similar to that obtained in the present research. The differences found with respect to the values reported in other investigations are mainly due to edaphoclimatic factors of the place of origin of the capulin harvest. Regarding the differences found in mineral concentrations among the four segregants, they could again be attributed to genetic differences as has been reported in other fruits and some vegetables (Reynoso-Camacho et al., 2006). There are no studies carried out on the variation of mineral content in capulin fruits in relationship to these factors, the present investigation is a contribution of mineral content in segregants. Therefore, the obtained results suggest that the consumption of capulin fruits could be an economical alternative for mineral intake in the population.

Proximal analysis

After fruit processing (40 °C for 5 min), ash content (minerals in the food) decreased only in three segregants P5-1P and P5-28P, as well as humidity content (Table 4); therefore, there was a loss of minerals (leachates) by transfer to the cooking water. According to Yagmur & Taskin (2011), most minerals in fruits and vegetables are water soluble, so it is common for these nutrients to pass from the tissue

Table 2. Total soluble solids content (°Brix), pH and color attributes in fresh fruit of four segregants of capulin (*Prunus serotina*).

Segregant	Total Soluble Solids (°Brix)	pH	Brightness (%)	Angle of tone Hue (°)	Chroma
P5-1F	15.88 ± 0.97 a	5.40 ± 0.18 a	23.34 ± 1.46 a	28.35 ± 3.82 a	17.16 ± 2.98 a
P5-3F	14.84 ± 1.43 b	4.21 ± 0.16 d	22.75 ± 1.69 a	19.38 ± 3.95 b	11.64 ± 3.82 b
P5-18F	14.92 ± 0.88 b	4.78 ± 0.16 b	21.22 ± 0.89 b	18.02 ± 2.93 b	9.44 ± 3.17 b
P5-28F	15.37 ± 0.88 ab	4.42 ± 0.20 c	20.95 ± 0.63 b	17.68 ± 2.68 b	6.18 ± 1.91 c

Values reported are the mean of 25 replicates ± standard deviation. Means with the same letter, in the same column are statistically equal (Tukey, 0.05).

Table 3. Mineral content (mg 100 g⁻¹ p.f.) in the fresh fruit pulp of four segregants of capulin (*Prunus serotina*).

Mineral	Segregant			
	P5-1F	P5-3F	P5-18F	P5-28F
P	40.28 ± 0.34 a	35.87 ± 0.24 c	35.85 ± 0.39 c	37.13 ± 0.41 b
K	106.72 ± 0.38 a	100.46 ± 0.46 c	104.99 ± 0.26 b	96.31 ± 0.17 d
Ca	22.63 ± 0.36 b	21.19 ± 0.25 c	16.43 ± 0.32 d	23.82 ± 0.43 a
Mg	24.57 ± 0.07 a	22.34 ± 0.21 b	16.97 ± 0.12 d	19.67 ± 0.42 c
Na	21.03 ± 0.39 ab	20.19 ± 0.42 b	17.45 ± 0.42 c	21.63 ± 0.05 a
Fe	0.67 ± 0.08 b	0.63 ± 0.00 b	0.53 ± 0.00 b	0.88 ± 0.04 a
Mn	0.16 ± 0.00 b	0.17 ± 0.00 b	0.20 ± 0.00 a	0.20 ± 0.01 a
Zn	0.28 ± 0.00 b	0.34 ± 0.00 a	0.30 ± 0.00 b	0.32 ± 0.00 a
Cu	0.02 ± 0.00 d	0.04 ± 0.00 b	0.03 ± 0.00 c	0.07 ± 0.00 a
B	0.99 ± 0.03 a	1.04 ± 0.00 a	0.90 ± 0.01 b	1.01 ± 0.02 a

Values represent the mean of 3 replicates; ± standard deviation. Means with the same letter, in the same row, are statistically equal (Tukey, 0.05).

Table 4. Proximal analysis (%) of the fresh fruits (F) and processed (P) fruits of four segregants of capulin (*Prunus serotina*).

Segregantng	Ashes	Humidity	Protein	Carbohydrates	Crude fiber
P5-1 F	0.771 ± 0.016 d	79.45 ± 0.26 b	1.79 ± 0.46 b	17.95 ± 0.25 ab	3.99 ± 0.06 ab
P 5-3 F	0.954 ± 0.004 a	81.21 ± 0.26 a	2.37 ± 0.01 a	15.52 ± 0.11 d	3.45 ± 0.06 d
P 5-18 F	0.911 ± 0.008 b	80.98 ± 0.66 a	1.82 ± 0.09 b	16.33 ± 0.76 cd	3.63 ± 0.17 cd
P5-28 F	0.912 ± 0.011 b	79.92 ± 0.02 b	1.83 ± 0.01 b	17.31 ± 0.10 bc	3.85 ± 0.01bc
P5-1 P	0.684 ± 0.008 e	79.26 ± 0.11 b	1.82 ± 0.01 b	18.21 ± 0.11 ab	4.04 ± 0.02 ab
P 5-3 P	0.856 ± 0.013 c	81.33 ± 0.09 a	1.17 ± 0.02 d	16.52 ± 0.09 cd	3.67 ± 0.02 cd
P5-18 P	0.841 ± 0.015 c	81.24 ± 0.16 a	1.40 ± 0.02 c	16.42 ± 0.13 cd	3.64 ± 0.03 cd
P5-28 P	0.821 ± 0.011c	78.95 ± 0.16 b	1.47 ± 0.02 c	18.74 ± 0.17 a	4.16 ± 0.04 a

Values represent the mean of 3 replicates; ± standard deviation. Means with the same letter, in the same column, are statistically equal (Tukey, 0.05).

to the process water; the external diffusion of minerals during cooking depends on the level of physical damage to the plant tissues and increases with thermal treatment in the cooking water; factors such as pH level, temperature, water-nutrient ratio, exposed surface area, among other factors affect mineral losses in the final product.

On the other hand, the fresh fruits of the four capulin segregants are an important source of carbohydrates, crude fiber, and protein (Table 4). No significant differences were found in fresh lipid content (F). Lipid content in all segregants was less than 0.03 % and therefore for l it was not reported in Table 5.

The P5-1F fruits had the highest carbohydrate and crude fiber concentrations among the studied segregants. Fruits of segregant P5-3F had the highest crude protein concentration. In this regard, Luna-Vázquez et al. (2013) reported lower carbohydrate values, similar crude fiber and higher protein values in capulin fruits (*P. serotina* subssp. *capuli*) (12.23, 3.58 and 2.10 %, respectively); but the fruit of the studied segregants presented higher values of carbohydrates and protein compared to those reported in cherry (*Prunus domestica*) (8.28 and 0.49 %, respectively) and grape (*Vitis vinifera*) (13.96 and 0.46 %, respectively).

Therefore, this fruit is a source of nutrients at low cost. It is important to highlight that the crude fiber value found in capulin of the studied segregants, between 18.36 to 19.41 % in dry weight, is higher than that reported by Blejan et al. (2023) in some by-products (dry mixture of peels, seeds and residual pulp after juice removal) of wild blueberries (*Vaccinium myrtillus* L.) and blackcurrants (*Ribes nigrum* L.) (11.84 and 15.50 % dry weight, respectively). Foods rich in fiber provide health benefits for the prevention and reduction of the risk of chronic diseases; the consumption of crude fiber has a laxative effect, that is why it is recommended by specialists to people suffering from constipation (Ioniță-Mîndrican et al., 2022). Regarding the effect of thermal treatment on carbohydrate and crude fiber contents, processed fruits (P) showed

higher concentrations compared to that of fresh fruit (F) (Table 4), due to the concentration of these nutrients as well as water loss from the fruit during thermal treatment. According to Ramalakshmi et al. (2021), nutrient loss during cooking depends on the temperature, length of treatment and the nutrient involved; carbohydrate loss during cooking is generally small and only after several minutes of cooking and at temperatures close to 100° C.

Finally, it is important to note that a reduction of up to 25 % in protein content was observed in processed fruits (P) with respect to fresh capulin (Table 4), with the exception of the fresh and processed segregant (P5-1F and P5-1P) whose content was statistically equal in both conditions. Considerable loss of soluble nutrients substances when dissolved or leached in the cooking water, such as proteins, water-soluble minerals and vitamins, is common (Deng et al., 2019).

Nutraceuticals content

Significant differences ($P \leq 0.05$) were found in the concentration of phenolic compounds, anthocyanins, flavonoids and vitamin C among the fresh fruits of the four segregants. Fresh fruit (F) of segregants P5-28F and P5-3F showed the highest concentrations of anthocyanins and flavonoid compounds. Regarding the concentrations of total flavonoids and vitamin C, the values were similar among all segregants, except for P5-1 F which presented the lowest concentrations of these metabolites (Table 5). Anttonen & Karjalainen, (2005) report that the content of phenolic components can vary significantly among cultivars of a species due to gene expression related to the biosynthesis of some metabolites in response to changes in the crop environment. Phenolic components in addition to their antioxidant capacity possess other mechanisms of action that explain their diverse beneficial effects on consumers (Potì et al., 2019).

Phytochemical studies of cultivars, varieties or segregants of a species allow planning breeding strategies, as

Chart 5. Content of nutraceutical compounds in fresh fruit (F) and processed (P) of four capulin segregants (*Prunus serotina*) by each 100 g of fresh weight.

Segregant	Phenolic Compounds (mg EAG)	Flavonoids (mg EQ)	Anthocyanins (mg ECyd-3-Gli)	Vitamin C (mg EAA)
P5-1 F	96.42 ± 3.09 e	28.39 ± 0.18 e	9.05 ± 0.20 e	33.87 ± 0.24 c
P5-3 F	331.57 ± 4.09 b	50.49 ± 0.83 a	19.69 ± 0.19 ^a	40.06 ± 0.55 a
P5-18 F	228.84 ± 5.95 d	48.68 ± 1.47 ab	16.46 ± 0.61 c	42.01 ± 0.93 a
P5-28 F	341.27 ± 3.09 b	50.25 ± 0.44 a	18.54 ± 0.32 ab	40.46 ± 0.77 a
P5-1 P	104.6 ± 2.14 e	31.30 ± 0.31d	8.44 ± 0.24 e	33.52 ± 0.34 c
P5-3 P	390.69 ± 3.24 a	49.58 ± 0.53 a	16.57 ± 0.34 c	40.06 ± 0.62 a
P5-18 P	305.27 ± 2.14 c	46.44 ± 0.53 b	10.77 ± 0.24 d	36.61 ± 0.40 b
P5-28 P	388.84 ± 0.86 a	42.01 ± 0.12 c	17.48 ± 0.29 bc	36.69 ± 0.54 b

Values represent the mean of 3 replicates; ± standard deviation. Means with the same letter, in the same column, are statistically equal (Tukey, 0.05). EAG: gallic acid equivalents, EQ: quercetin equivalents, ECyd-3-Gli: cyanidin-3-glucoside, EAA: ascorbic acid equivalents.

well as selecting individuals with high content of active ingredients or commercial interest as natural colorants, nutraceutical ingredients, and antioxidants for the food industry or to improve the content of healthy compounds in capulin fruits.

It is important to note that the values of phenolic compounds and flavonoids (4.69-17.64 mg EAG · g⁻¹ y 1.38-2.68 mg EQ · g⁻¹ p.s., respectively) found in the four studied segregants and transformed in the same concentration units were lower than those reported by Hernández Rodríguez et al. (2019) in wild capulin collected in Zacatlán, Puebla, Mexico (14.40-26.96 mg EAG · g⁻¹ p.s., 16.56-9.23 mg EQ · g⁻¹ p.s. and 0.04-0.66 mg cyanidin-3-glucoside (C-3-G) · g⁻¹ p.s.); in contrast, higher anthocyanin concentrations (0.44-1.05 mg C-3-G equivalents per g, dry weight) were found in all the studied segregants. Ordaz-Galindo et al. (1999) reported anthocyanin values in capulin fruits (*Prunus serotina*) (31.7 mg equivalents of cyanidin -3-glycoside · 100 g⁻¹ p.f.) similar to those reported in the present research.

On the other hand, the concentration of flavonoids found in all the segregants was lower than that of total phenolic components, possibly because some flavonoids could be found forming procyanidins (condensed tannins) as in other fruits (Cui et al., 2006).

The vitamin C content was statistically equal among the fresh fruits of segregants P5-3F, P5-18F and P5-28F, the lowest value of this metabolite was present in the fresh fruits of segregants P5-1F. There are no studies on the content of this vitamin in capulin.

On the other hand, thermal treatment had a significant effect on the content of nutraceutical compounds among the fruits of the four segregants. The content of phenolic components obtained a significant increase in the fruits of the four segregants post-thermal treatment (17 %), which

could be due to the concentration of these nutrients by the loss of water from the fruit during thermal treatment, as was observed in carbohydrates.

Segregants P5-3F and P5-18F showed no significant differences in flavonoid content after thermal treatment, while segregant P5-28P showed the greatest decrease in these metabolites. Flavonoids are also phenolic compounds with antioxidant potential found in vegetables and fruit; in the latest two decades epidemiological studies have shown a relationship between flavonoid consumption and the low incidence of degenerative diseases (Toh et al., 2013). The mechanisms of action of each group of phytochemicals in capulin are unknown, but the synergistic effect of these bioactives make it a food with notable functional properties, mainly the fruits of the segregant P5-3F and P5-28F.

The effect of the thermal treatment also resulted in a significant average decrease of 16 % of anthocyanin content in P5-3F and P5-18F segregants (Table 5). Anthocyanin levels may be affected by the temperature of process. Oliveira et al. (2010) observed a reduction in anthocyanin content in blueberries between 12 and 42 % during progressive heating from 12° to 99 °C for 60 min, the same phenomenon was found in the thermal treated capulin studied in the present research.

Vitamin C content (Table 6) showed significant differences only between fresh and processed fruits of segregants P5-18F and P5-28F, where a decrease in content was generated (12.8 and 9.3 %, respectively). The vitamin C content in fresh capulin fruits of the four analyzed segregants was higher than that reported by Garcia et al. (2006) in banana (8 – 16 mg · 100 g⁻¹) and green apple (3-30 mg · 100 g⁻¹). Vitamin C plays a very important role in human metabolism, it is essential for the development and function of the nervous system, it is part of the mechanisms of cicatrization, biosynthesis of collagen and different neurotransmitters (Kükürt & Gelen, 2024).

Table 6. Antioxidant capacity in fresh (F) and processed fruits (P) of four segregants of capulin (*Prunus serotina*).

Segregant	Antioxidant Capacity ($\mu\text{ mol} \cdot \text{ET}100 \text{ g}^{-1} \text{ pf}$)	Inhibition (%)
P5-1 F	1326.084 \pm 47.27 c	54.17 \pm 2.17 b
P5-3 F	1800.81 \pm 23.23 b	92.25 \pm 3.28 a
P5-18 F	1390.40 \pm 2.88 c	57.13 \pm 0.13 b
P5-28 F	2154.05 \pm 71.48 a	95.77 \pm 1.13 a
P5-1 P	1816.94 \pm 8.81 b	91.36 \pm 0.40 a
P5-3 P	2252.06 \pm 22.22 a	96.76 \pm 1.02 a
P5-18 P	2145.89 \pm 76.11 a	91.87 \pm 3.50 a
P5-28 P	2134.66 \pm 8.78 a	97.84 \pm 0.43 a

Values represent the mean of 3 replicates; \pm standard deviation. Means with the same letter, in the same column, are statistically equal (Tukey, 0.05). ET: trolox equivalents.

Finally, it is important to point that the fresh fruits of the P5-3F segregant were the ones in which nutraceutical compounds were less affected to the thermal treatment (except for the concentration of anthocyanins), which corresponded with higher antioxidant activity (Table 6), for this reason, it is recommended as a segregant with potential to be processed.

Antioxidant capacity

The antioxidant capacity of the fresh and processed fruits of the four segregants showed significant differences ($P \leq 0.05$) (Table 6). The highest antioxidant capacity values were observed in the fresh fruit of segregant P5-28F, followed by P5-3F. The fresh fruits of these segregants had the highest content of anthocyanidins, phenolic compounds, flavonoids and vitamin C. The processed fruits of the four segregants showed an increase of 28 % in the antioxidant capacity content; as well, in their average of free radical inhibitory capacity (34 %), which could be explained by the increase of phenolic compounds (17 %) as mentioned above in the present study. The antioxidant capacity obtained in fresh and processed fruits of the four capulin segregants ($1326.08 \pm 47.27 - 2252.06 \pm 22.22 \mu\text{mol ET} \cdot 100 \text{ g}^{-1} \text{ p.f.}$) was similar to the values reported by Luna-Vázquez et al. (2013) ($1455.2 \pm 92.5 - 2056.7 \pm 108.0 \mu\text{mol ET} \cdot 100 \text{ g}^{-1} \text{ p.f.}$) in fresh fruits of the same species. On the other hand, similar research carried by García-Mateos et al. (2013) on 20 different tejocote genotypes and Ballistreri et al. (2013) on 24 sweet cherries (*P. avium*), varieties showed that genetic factor could explain variations in the nutraceutical characteristics of capulin segregants.

Conclusions

The capulin fruit of the four studied segregants is a source of nutrients (protein, fiber, carbohydrates, P, K, Ca, Mg and Fe) and antioxidant compounds (phenolics, anthocyanins and vitamin C) at a low cost. The fruit of segregant P5-1F had the highest carbohydrate content, total soluble solids

and pH, important quality attributes for marketing a fruit; however, it had the lowest nutraceutical value in the fresh and processed condition. In contrast, the fruits of P5-3 segregant had the highest protein values and nutraceutical potential due to their high concentrations of phenolic compounds, flavonoids, anthocyanins, vitamin C and antioxidant activity in its fresh (P5-3F) and processed (P5-3P). Fresh fruits from segregants P5-3F and P5-28F were statistically superior in anthocyanin and flavonoid content, sharing this superiority in vitamin C content with fresh fruits from segregant P5-18F. The fresh fruits of the P5-28F showed the highest antioxidant capacity, associated with their high concentration of nutraceutical compounds. The factors thermal treatment (40 °C for 5 min) and capulin segregant had a joint significant effect on the nutritional and nutraceutical value of fresh and processed fruits. The fruits of P5-3P segregant tolerated the thermal treatment the most, so the fruits showed the least effects in the nutraceutical components and the highest value of antioxidant activity, for this reason it is recommended as a segregant with potential to be processed in order to generate added value.

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References

- Alcántar-González, G., & Sandoval-Villa, M. (1999). Manual de Análisis Químico de Tejido Vegetal. Sociedad Mexicana de la Ciencia del Suelo, A. C. 1999. Chapingo, México.
- Anttonen, M. J., & Karjalainen, R. O. (2005). Environmental and genetic variation of phenolic compounds in red raspberry. *Journal of Food Composition and Analysis*, 18(8), 759–769. <https://doi.org/10.1016/j.jfca.2004.11.003>

- AOAC. (2005). *Official Methods of Analysis*. (18th Ed.). Association of Official Analytical Chemist.
- Ballistreri, G., Continella, A., Gentile, A., Amenta, M., Fabroni, S., & Rapisarda, P. (2013). Fruit quality and bioactive compounds relevant to human health of sweet cherry (*Prunus avium* L.) cultivars grown in Italy. *Food Chemistry*, 140(4), 630–638. <https://doi.org/10.1016/j.foodchem.2012.11.024>
- Baxter, C. J., Carrari, F., Bauke, A., Overy, S., Hill, S. A., Quick, P. W., Fernie, A. R., & Sweetlove, L. J. (2005). Fruit Carbohydrate Metabolism in an Introgression Line of Tomato with Increased Fruit Soluble Solids. *Plant and Cell Physiology*, 46(3), 425–437. <https://doi.org/10.1093/pcp/pci040>
- Blejan, A. M., Nour, V., Păcularu-Burada, B., & Popescu, S. M. (2023). Wild bilberry, blackcurrant, and blackberry by-products as a source of nutritional and bioactive compounds. *International Journal of Food Properties*, 26(1), 1579–1595. <https://doi.org/10.1080/10942912.2023.2224530>
- Cui, T., Nakamura, K., Tian, S., Kayahara, H., & Tian, Y.-L. (2006). Polyphenolic Content and Physiological Activities of Chinese Hawthorn Extracts. *Bioscience, Biotechnology, and Biochemistry*, 70(12), 2948–2956. <https://doi.org/10.1271/bbb.60361>
- Chang, C.-C., Yang, M.-H., Wen, H.-M., & Chern, J.-C. (2002). Estimation of total flavonoid content in propolis by two complementary colometric methods. *Journal of Food and Drug Analysis*, 10(3), 178–182. <https://doi.org/10.3821/2224-6614.2748>
- Deng, L.-Z., Mujumdar, A. S., Zhang, Q., Yang, X.-H., Wang, J., Zheng, Z.-A., Gao, Z.-J., & Xiao, H.-W. (2019). Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes – a comprehensive review. *Critical Reviews in Food Science and Nutrition*, 59(9), 1408–1432. <https://doi.org/10.1080/10408398.2017.1409192>
- Dürüst, N., Sümengen, D., & Dürüst, Y. (1997). Ascorbic Acid and Element Contents of Foods of Trabzon (Turkey). *Journal of Agricultural and Food Chemistry*, 45(6), 2085–2087. <https://doi.org/10.1021/jf9606159>
- Fresnedo-Ramírez, J., Segura, S., & Muratalla-Lúa, A. (2011). Morphovariability of capulín (*Prunus serotina* Ehrh.) in the central-western region of Mexico from a plant genetic resources perspective. *Genetic Resources and Crop Evolution*, 58(4), 481–495. <https://doi.org/10.1007/s10722-010-9592-2>
- García, G., García, A., Mejía, Ó., Clavijo, D., Hernández, S., Báez, S., & Cobos, C. (2006). Aspectos bioclinicos y patobiológicos de la vitamina C en la especie humana. *CES Medicina*, 20(2), 3479–3495. <https://doi.org/10.3390/molecules20023479>
- García-Mateos, R., Ibarra-Estrada, E., & Nieto-Angel, R. (2013). Antioxidant compounds in hawthorn fruits (*Crataegus* spp.) of Mexico. *Revista Mexicana de Biodiversidad*, 84(4), 1298–1304. <https://doi.org/10.7550/rmb.35675>
- García-Aguilar, L., Rojas-Molina, A., Ibarra-Alvarado, C., Rojas-Molina, J., Vázquez-Landaverde, P., Luna-Vázquez, F., & Zavala-Sánchez, M. (2015). Nutritional Value and Volatile Compounds of Black Cherry (*Prunus serotina*) Seeds. *Molecules*, 20(2), 3479–3495. <https://doi.org/10.3390/molecules20023479>
- Giusti, M. M., & Wrolstad, R. E. (2001). Characterization and Measurement of Anthocyanins by UV-Visible Spectroscopy. *Current Protocols in Food Analytical Chemistry*, 00(1). <https://doi.org/10.1002/0471142913.faf0102s00>
- Guzmán, F. A., Segura-Ledesma, S. D., & Almaguer-Vargas, G. (2020). El capulín (*Prunus serotina* Ehrh.): Árbol multipropósito con potencial forestal en México. *Madera y Bosques*, 26(1). <https://doi.org/10.21829/myb.2020.2611866>
- Hernández Rodríguez, G., Espinosa-Solares, T., Perez-Lopez, A., Salgado-Escobar, I., & Guerra-Ramirez, D. (2019). Antioxidant capacity of capulín (*Prunus serotina* subsp. Capuli (Cav). McVaugh) fruit at different stages of ripening. *Ecosistemas y Recursos Agropecuarios*, 6(16), 35–44. <https://doi.org/10.19136/era.a6n16.1947>
- Ibarra-Alvarado, C., Rojas, A., Luna, F., Rojas, J., Rivero-Cruz, B., & Rivero-Cruz, J. (2009). Vasorelaxant constituents of the leaves of *Prunus serotina* “Capulín”. *Revista Latinoamericana de Química*. <https://www.semanticscholar.org/paper/Vasorelaxant-constituents-of-the-leaves-of-Prunus-Ibarra-Alvarado-Rojas/ad6ce32ea8c6eba2a9e8adeeb937e23764d52be>
- Ioniță-Mindrican, C.-B., Ziani, K., Mititelu, M., Oprea, E., Neacșu, S. M., Moroșan, E., Dumitrescu, D.-E., Roșca, A. C., Drăgănescu, D., & Negrei, C. (2022). Therapeutic Benefits and Dietary Restrictions of Fiber Intake: A State of the Art. Review. *Nutrients*, 14(13), 2641. <https://doi.org/10.3390/nu14132641>
- Jimenez, M., Castillo, I., Azuara, E., & Beristain, C. I. (2011). Actividad antioxidante y antimicrobiana de extractos de capulín (*Prunus serotina* subsp capuli). *Revista mexicana de ingeniería química*, 10(1), 29–37.
- Kükürt, A., & Gelen, V. (2024). Understanding Vitamin C: Comprehensive Examination of Its Biological Significance and Antioxidant Properties. En A. Kükürt & V. Gelen (Eds.), *Ascorbic Acid—Biochemistry and Functions*. IntechOpen. <https://doi.org/10.5772/intechopen.114122>
- López-Hernández, E. F., Santiago-Mejía, H., & Ortiz, Y. G. (2024). Conocimiento etnobotánico asociado al árbol de capulín (*Prunus serotina* Ehrh.) en comunidades mazahua de Jocotitlán, Estado de México, México. *Etnobiología*, 22(1), Article 1.
- Luna-Vázquez, F., Ibarra-Alvarado, C., Rojas-Molina, A., Rojas-Molina, J., Yahia, E., Rivera-Pastrana, D., Rojas-Molina, A., & Zavala-Sánchez, Á. M. (2013). Nutraceutical Value of Black Cherry *Prunus serotina* Ehrh. Fruits: Antioxidant and Antihypertensive Properties. *Molecules*, 18(12), 14597–14612. <https://doi.org/10.3390/molecules181214597>
- McGuire, R. G. (1992). Reporting of Objective Color Measurements. *HortScience*, 27(12), 1254–1255. <https://doi.org/10.21273/HORTSCI.27.12.1254>
- Oliveira, C., Amaro, L. F., Pinho, O., & Ferreira, I. M. P. L. V. O. (2010). Cooked blueberries: Anthocyanin and anthocyanidin degradation and their radical-scavenging activity. *Journal of Agricultural and Food Chemistry*, 58(16), 9006–9012. <https://doi.org/10.1021/jf101923w>
- Ordaz-Galindo, A., Wesche-Ebeling, P., Wrolstad, R. E., Rodriguez-Saona, L., & Argaiz-Jamet, A. (1999). Purification and identification of Capulín (*Prunus serotina* Ehrh) anthocyanins. *Food Chemistry*, 65(2), 201–206. [https://doi.org/10.1016/S0308-8146\(98\)00196-4](https://doi.org/10.1016/S0308-8146(98)00196-4)
- Pairon, M. C., & Jacquemart, A.-L. (2005). Disomic Segregation of Microsatellites in the Tetraploid *Prunus serotina* Ehrh. (Rosaceae). *Journal of the American Society for Horticultural Science*, 130(5), 729–734. <https://doi.org/10.21273/JASHS.130.5.729>
- Pathania, S., Itle, R. A., Chávez, C. R., Lema, L. F., Caballero-Serrano, V., Carrasco, J. C., & Chavez, D. J. (2022). Fruit Characterization of

- Prunus serotina* subsp. Capuli. *Horticulturae*, 8(9), 838. <https://doi.org/10.3390/horticulturae8090838>
- Petitpierre, B., Pairon, M., Broennimann, O., Jacquemart, A. L., Guisan, A., & Besnard, G. (2009). Plastid DNA variation in *Prunus serotina* var. *Serotina* (Rosaceae), a North American tree invading Europe. *European Journal of Forest Research*, 128(5), 431–436. <https://doi.org/10.1007/s10342-009-0287-1>
- Poti, F., Santi, D., Spaggiari, G., Zimetti, F., & Zanotti, I. (2019). Polyphenol Health Effects on Cardiovascular and Neurodegenerative Disorders: A Review and Meta-Analysis. *International Journal of Molecular Sciences*, 20(2), 351. <https://doi.org/10.3390/ijms20020351>
- Potter, D. (2011). *Prunus*. En C. Kole (Ed.), *Wild Crop Relatives: Genomic and Breeding Resources* (pp. 129–145). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-16057-8_7
- Ramalakshmi, K., Subhapiya, P., Ananthavalli, K., Sarada, K., & Shanmugapriya, D. (2021). Impact of cooking on nutrients in selected vegetables. *International Journal of Engineering Research and Application*, 11(2), 31-35. <https://doi.org/10.9790/9622-1102023135>
- Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine*, 26(9–10), 1231–1237. [https://doi.org/10.1016/S0891-5849\(98\)00315-3](https://doi.org/10.1016/S0891-5849(98)00315-3)
- Reynoso-Camacho, R., Ramos-Gómez, M., Loarca-Piña, G., Guevara-González, R., & Torres-Pacheco, I. (2006). Bioactive components in common beans (*Phaseolus vulgaris* L.). [https://www.semanticscholar.org/paper/Bioactive-components-in-common-beans-\(Phaseolus-Reynoso-Camacho-Ramos-G%C3%B3mez/6f298346344c2ea4b0c585e7c7b3c1df9f23f2ab](https://www.semanticscholar.org/paper/Bioactive-components-in-common-beans-(Phaseolus-Reynoso-Camacho-Ramos-G%C3%B3mez/6f298346344c2ea4b0c585e7c7b3c1df9f23f2ab)
- Román-Cortés, N. R., García-Mateos, Ma. del R., Castillo-González, A. Ma., Sahagún-Castellanos, J., & Jiménez-Arellanes, Ma. A. (2018). Características nutricionales y nutraceuticas de hortalizas de uso ancestral en México. *Revista Fitotecnia Mexicana*, 41(3), 245–253. <https://doi.org/10.35196/rfm.2018.3.245-253>
- SAS Institute Inc. (2002). *SAS/STAT Software, Version 9.00* [Statistical Analysis System 9.0 for Windows].
- SIAP. (2024). *Sistema de Información Agroalimentaria de Consulta* (Versión 2024) [Software]. Servicio de Información Agroalimentaria y Pesquera.
- Swain, E., Li, C. P., & Poulton, J. E. (1992). Development of the Potential for Cyanogenesis in Maturing Black Cherry (*Prunus serotina* Ehrh.) Fruits. *Plant Physiology*, 98(4), 1423–1428. <https://doi.org/10.1104/pp.98.4.1423>
- Telichowska, A., Kobus-Cisowska, J., & Szulc, P. (2020). Phytopharmacological Possibilities of Bird Cherry *Prunus padus* L. and *Prunus serotina* L. Species and Their Bioactive Phytochemicals. *Nutrients*, 12(7), 1966. <https://doi.org/10.3390/nu12071966>
- Toh, J. Y., Tan, V. M. H., Lim, P. C. Y., Lim, S. T., & Chong, M. F. F. (2013). Flavonoids from Fruit and Vegetables: A Focus on Cardiovascular Risk Factors. *Current Atherosclerosis Reports*, 15(12), 368. <https://doi.org/10.1007/s11883-013-0368-y>
- Waterman, P. G., & Mole, S. (1994). Analysis of phenolic plant metabolites. *Methods in Ecology*. Blackwell Scientific Publications, Oxford. 238 p.
- Yagmur, C., & Taskin, M. (2011). Study on changes in mineral content of plum (*Prunus domestica*) and strawberry (*Fragaria*—*ananassa*) during canning. *The Indian Journal of Agricultural Sciences*, 81(8), Article 8. <https://epubs.icar.org.in/index.php/IJAgS/article/view/8424>