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Fruit Characterization of *Prunus serotina* subsp. *capuli*

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Abstract: *Prunus serotina* is divided into five subspecies. Among these, *P. serotina* subsp. *capuli*, commonly known as capuli, is native to Central and South America. Its fruits are big, sweet, and consumed by locals in various forms, with the Ecuadorian Andes region providing the best fruit forms of capuli. The objective of this study was to characterize a collection of different genotypes of capuli's fruit, and their endocarps, found growing in the wild in the Chimborazo, Tungurahua, and Cotopaxi provinces of Ecuador. The fruits were characterized for weight (11.7–50.3 g), diameter (12.4–21.7 mm), height (11.4–19.7 mm), and soluble solids content (SSC) (13.4–27.6 °Brix) across two years. Similarly, the endocarps' diameters (7.5–12.2 mm) and heights (8.1–13.6 mm) were measured. Significant differences were found for all the fruit and endocarp variables studied. A multivariate analysis showed that all the fruit and endocarp size characteristics, except SSC, were positively correlated with each other within a season. No clear population differentiation was seen among the genotypes from different provinces, suggesting a lack of clear morphological differentiation. The future breeding and selection of a capuli with superior, commercial, large fruit and a high SSC shows great potential.

Keywords: capuli; black cherry; breeding; morphological characterization; fruit; endocarp; Ecuador



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1. Introduction

Prunus serotina Ehrh. is commonly known as a black cherry [1]. It is commercially important due to its high-quality timber, which is used for making scientific and professional instrument boxes, furniture, and cabinets [2]. This species was introduced in central Europe in the 17th century as an ornamental species but now it is considered as an invasive species in western Europe [3–5]. Similarly, *P. serotina* has been evaluated as a rootstock for other *Prunus* species [6].

The *Prunus serotina* tree grows in cool, moist, temperate climates, with optimum and evenly dispersed rainfall [1]. *Prunus serotina* is further classified into the following five different subsp.: *P. serotina* subsp. *serotina*; *P. serotina* subsp. *virens* (Woot. and Standl.) McVaugh; *P. serotina* subsp. *hirsuta* (Elliot) McVaugh; *P. serotina* subsp. *eximia* (Small) McVaugh; and *P. serotina* subsp. *capuli* (Cav. Ex Spreng.) McVaugh [7]. These subspecies have a broad distribution range throughout North, Central, and South America, each occupying distinct geographical regions and each having different morphological characteristics. Among the five subspecies, *P. serotina* subsp. *capuli*, or capuli, is a unique subspecies, with a presence in Mexico, Ecuador, Colombia, and Guatemala, and with superior forms found in the Ecuadorian Andes [7].

The capuli's fruit has a depressed globose shape, with a light maroon to deep purplish skin color. Its flesh is a pale brownish green, melting and juicy. The fruits have a sweet vinous flavor, with a taste of bitterness because of the skin [8]. Its flesh constitutes the mesocarp and its skin the exocarp of the fruit. The endocarp is the stone or pit. These

fruits are abundantly available in Ecuadorian markets from December to February and are mostly eaten fresh. They can also be stewed, preserved, or made into wine or jam [9]. Tea and syrups made from capuli leaves are used in the treatment of hypertension, stomach problems, diarrhea, colds, malaria, and coughs [10]. Research has shown that capuli's fruit has a high number of phenolic compounds, with antihypertensive and antioxidant effects [11,12]. Its consumption can be beneficial in preventing health issues such as hypertension and cardiovascular diseases [11].

The roasted seeds of capuli's fruit are used as snacks in Mexico [13]. Capuli's seeds have a protein content in their raw (37.95%) and toasted (36.55%) forms, which is higher than that in almonds and peanuts. The fat content in the raw (40.37%) and toasted seeds (39.97%) was found to be lower than that in almonds (49.64%), but not significantly different to that in peanuts (41.12%) [14]. Black cherry seed oil is rich in oleic (35%), linoleic (27%), and α -eleostearic acid (27%) [15]. Despite its significant health and nutritional benefits, there are no commercial capuli cultivars or breeding programs in the world.

Research regarding the capuli fruit's morphological characteristics is fundamental for the establishment of future capuli breeding programs. Fruit size and firmness are among the most important morphological characteristics for evaluating a fruit's economic value [16]. For example, fruit size and diameter are the main morphological characteristics on which sweet cherries (*Prunus avium* L.) are commercially graded in the United States [17]. Similar grading and commercialization exists for other fruits and in other countries in which fruit size is one of the most important characteristics. Christensen [16] studied sweet cherry cultivars from Denmark and found the average sweet cherry size to be 6.6 g per fruit. Khadivi et al. [18] studied the morphological characteristics of 45 sweet cherry, 62 sour cherry, and 39 duke cherry [*Prunus* \times *gondouinii* (Poit. and Turpin.) Schneid.] cultivars from Iran. The fruits' length varied from 18.9 to 28.5 mm for the sweet cherry cultivars, 11.2 mm to 14.6 mm for the sour cherry cultivars (*Prunus cerasus* L.), and 15.4 to 18.6 mm for the duke cherry cultivars. For fruit weight, the sweet cherry cultivars varied from 4.4 to 8.9 g, sour cherry cultivars from 1.4 to 2.7 g, and from 4.4 to 6.0 g for the duke cherry cultivars.

In North America, the average diameter of the *P. serotina* fruits growing in central Mississippi varied from 7–10 mm [19]. Marquis [20] also reported the diameter of the black cherry fruit to be approximately 10 mm. Limited studies have been published regarding the capuli fruit's morphology. The presence of superior fruit genotypes of *P. serotina* subsp. *capuli* in the Ecuadorian Andes creates a unique opportunity for future breeding and selection. This study aims to characterize a collection of different genotypes of capuli's fruit and their endocarps (stones, pits) found growing in the wild in the Chimborazo, Tungurahua, and Cotopaxi provinces of Ecuador. Capuli fruit's characterization will help us to understand more about this species' natural morphological variation, which will further aid in the establishment of future capuli breeding programs for superior fruit, with commercial attributes.

2. Materials and Methods

2.1. Plant Material

Fruit of 24 *P. serotina* subsp. *capuli* genotypes were collected in 2016 and 2019 from three Ecuadorian provinces (Chimborazo, Cotopaxi, and Tungurahua) in the Andes region. Plant material collection was performed in accordance with the plan for access to genetic resources, made by Ecuador's Minister of Environment—collection permit MAE-DNB-CM-2019-0107P37-16-00098. Each genotype was given a unique ID, based on their collection site (Table 1). Genotypes were selected to represent a broad geographical range (~5–10 Km separation between collection sites) in the region (Figure 1). Generally, one individual tree/genotype was used per collection site, however, if more than two trees were observed per location, then fruit from one tree was randomly selected to represent that site.



Figure 1. Map representing collection sites of *Prunus serotina* subsp. *capuli* genotypes, collected from 3 different provinces of Ecuador in 2016 and 2019.

Table 1. List of *Prunus serotina* subsp. *capuli* genotypes, collected for fruit evaluation in the Andes region of Ecuador.

Collection (No.)	Genotype ID ^z	Country	Province	Latitude	Longitude
1	PserCO01	Ecuador	Cotopaxi	1°7'36.1" S	78°35'21.2" W
13	PserCO13	Ecuador	Cotopaxi	0°53'2" S	78°39'15.7" W
14	PserCO14	Ecuador	Cotopaxi	0°53'22.9" S	78°37'30.7" W
16	PserCO16	Ecuador	Cotopaxi	0°53'44.7" S	78°37'5" W
21	PserCO21	Ecuador	Cotopaxi	0°59'2.5" S	78°36'6.3" W
22	PserCO22	Ecuador	Cotopaxi	0°59'2.1" S	78°36'5.6" W
26	PserCO26	Ecuador	Cotopaxi	1°5'50.9" S	78°36'10.2" W
31	PserCO31	Ecuador	Cotopaxi	1°6'23.3" S	78°36'28.1" W
41	PserTU41	Ecuador	Tungurahua	1°24'8.9" S	78°38'2.2" W
43	PserTU43	Ecuador	Tungurahua	1°23'26" S	78°37'25.8" W
48	PserTU48	Ecuador	Tungurahua	1°21'5" S	78°36'45.2" W
53	PserTU53	Ecuador	Tungurahua	1°18'49.9" S	78°38'19" W

Table 1. Cont.

Collection (No.)	Genotype ID ^z	Country	Province	Latitude	Longitude
57	PserTU57	Ecuador	Tungurahua	1°17'49.3" S	78°37'14.1" W
67	PserTU67	Ecuador	Tungurahua	1°18'49" S	78°32'46.9" W
70	PserTU70	Ecuador	Tungurahua	1°20'2.3" S	78°33'51.8" W
71	PserTU71	Ecuador	Tungurahua	1°19'23.1" S	78°34'19.1" W
77	PserTU77	Ecuador	Tungurahua	1°21'11.3" S	78°34'58.5" W
94	PserCH94	Ecuador	Chimborazo	1°34'59.7" S	78°32'17.4" W
101	PserCH101	Ecuador	Chimborazo	1°37'3.3" S	78°35'49.3" W
108	PserCH108	Ecuador	Chimborazo	1°35'45.3" S	78°40'56.8" W
110	PserCH110	Ecuador	Chimborazo	1°35'21.2" S	78°41'17.3" W
113	PserCH113	Ecuador	Chimborazo	-	-
132	PserCH132	Ecuador	Chimborazo	1°41'47" S	78°38'39" W
142	PserCH142	Ecuador	Chimborazo	1°38'46.4" S	78°42'27.2" W

^z ID: first letter represents the genus (*P* = *Prunus*), next three letters represent the species (*ser* = *serotina*), and the following letters represented the province of origin in Ecuador and collection number (CO01 = Cotopaxi collection 01).

2.2. Fruit and Endocarp Measurements

Ripe fruits were collected in Ziploc bags and stored in a cooler with ice, after collection in February of 2016 and 2019 (Figure 2). Samples were then transported to the Escuela Politécnica del Chimborazo (ESPOCH) in Riobamba, Ecuador. Fruits were then evaluated for the following characteristics: weight of ten fruits (g), fruit diameter (mm) (measurement along the equatorial plane of the fruit at the widest point), fruit height (mm) (measurement from stem to the tip end of the fruit), and soluble solids content (SSC, °Brix). The flesh was separated from the endocarp after fruit measurements were taken. Endocarps were washed and left to dry for 48 h in paper towels. Endocarp diameter (mm) (measurement along the equatorial plane of the endocarp at the widest point) and height (mm) (measurement from stem to the tip end of the endocarp) were measured (Figure 3).



Figure 2. Fruits of *Prunus serotina* subsp. *capuli*, genotype PserTU48, collected in the Andes region of Ecuador in 2016. A US one cent coin was used as a size reference (diameter 19.05 mm).



Figure 3. Endocarps of *Prunus serotina* subsp. *capuli* genotype PserTU77, collected in the Andes region of Ecuador in 2016. A US one cent coin was used as a size reference (diameter 19.05 mm).

All measurements of size were completed using a digital caliper (Traceable[®] Carbon Fiber Calipers, Fisher Sci., Hampton, HN, USA). Weights were taken using a generic-brand digital balance. SSC was measured using a hand-held refractometer, from juice obtained from the flesh (Atago CO., LTD., Tokyo, Japan).

Three replicates of ten fruits per genotype were weighed (g). Five replicates of individual fruit and endocarp representatives of each genotype were measured for diameter (mm) and height (mm). SSC (°Brix) was measured for five individual fruit representatives of each genotype.

2.3. Statistical Analyses

Analyses of variance were performed on all fruit and endocarp parameters, with genotype, year, and genotype \times year as main effects in SAS 9.4 (SAS Institute Inc.; Cary, NC, USA), using PROC GLIMMIX. Means were separated using LSD test, with a significance level of $p \leq 0.05$. Multivariate analyses were performed for all parameters within the 2016 and 2019 seasons. PCA (Principal Component Analysis) was performed for both the years 2016 and 2019, with JMP[®] v.14 (SAS Institute Inc., Cary, NC, USA).

3. Results and Discussion

Prunus serotina subsp. *capuli* is known in Ecuador as “capuli”. It plays an important part in the life of the Ecuadorian people and other Andean countries. There are no known commercial types available in Ecuador, with most of the fruit production obtained from individuals in the wild.

3.1. Fruit Measurements

The fruit and endocarps’ characteristics were evaluated for 24 capuli genotypes, collected in Ecuador in the 2016 and 2019 seasons. There were statistically significant differences ($p \leq 0.05$) when comparing data across the seasons for fruit diameter, fruit height, ten fruit weight, the SSC, endocarp diameter, and endocarp height. The differences among the genotypes were identified for all the variables evaluated ($p \leq 0.05$). No statistically

significant differences were identified among the replicates for all variables ($p > 0.05$), except for endocarp height. Due to the variation present across the years, hereafter, all the analyses were performed in within-year comparisons.

The fruits' diameters varied from 12.8 to 19.1 mm in 2016 and from 12.4 to 21.7 mm in 2019. The largest fruit diameter was observed for PserTU77 (19.1 mm) in 2016, and for PserTU53 (21.7 mm) in 2019. The smallest fruit diameter was reported for PserCH94 (12.8 mm) in 2016, and PserCO13 (12.4 mm) in 2019 (Table 2). For fruit height, the values varied from 11.4 to 17.7 mm (2016) and from 12.2 to 19.7 mm (2019). Fruit from PserTU43 had the highest height value for 2016 (17.7 mm), and PserTU41 and PserTU53 had the highest fruit height for 2019 (19.7 mm) (Table 2).

Limited studies have been published regarding capuli fruit's morphology. McVaugh [7] characterized the fruit size of capuli. He reported a diameter approximately 20–25 mm. Vasco et al. [21] reported that the fruit of Ecuadorian capuli was 10–30 mm in diameter. Similarly, Avendaño-Gómez et al. [22] reported the average length of the capuli fruit found in Tlaxcala, Mexico, was 1.7 ± 0.2 cm, with a diameter of 1.5 ± 0.2 cm. The results from the research presented (Table 2) were consistent for *P. serotina* subsp. *capuli*. In the case of its sister species, Bonner [19] reported the average diameter of North American black cherry fruit to be 7–10 mm. Capuli fruit was generally larger than the fruit data reported for *P. serotina* subsp. *serotina* [19,22]. A variation in fruit size and morphology has also been observed in other *Prunus* species. Milošević and Milošević [23] reported the dimensions for sour cherry cultivars “Oblačinska” and “Cigančica” as follows: fruit length (between 14.85 ± 0.12 mm and 14.27 ± 0.19 mm, respectively) and fruit width (between 15.50 ± 0.09 mm and 15.23 ± 0.15 mm, respectively).

As previously described, fruit size is an important characteristic, which is used to evaluate a produce value for marketing and commercialization [16]. For example, this is an important standard used for the commercialization of sweet cherries. Different countries have different size standards. Spain has standards in which cherries with a 25 mm diameter are considered in the “extra category”, whereas, in Summerland (Canada) the ideal cherry diameter is 29–30 mm [24]. In the US, cherries with a diameter of 30 mm were preferred by consumers [25]. In addition, Kappel et al. [26] described an ideal sweet cherry for the North American market as 11–12 g in weight and 29–30 mm in diameter.

The ten fruit weight for *P. serotina* subsp. *capuli* varied from 11.7 to 43.7 g (2016) and from 12.0 to 50.3 g (2019). The highest value for the ten fruit weight in 2016 was found for PserTU48 (43.7g) and for PserTU53 (50.3g) in 2019. The smallest ten fruit weight was found consistently for PserCO13—15.4 g in 2016 and 12 g in 2019 (Table 2). The individual fruit weight was recorded for the largest and smallest fruit in each fruit lot (data not shown). The highest individual fruit weight was observed for PserTU48 and PserTU53: 5.82 g and 3.92 g (2016), and 4 g and 5 g (2019), respectively. These individual weights are consistent with the ten fruit weight average. Vasco et al. [21] studied the weight of capuli fruits from Ecuador and reported an individual fruit weight of between 2–8 g. Khadivi et al. [18] reported the average fruit weight of 45 sweet cherry cultivars (4.4 to 8.9 g), 62 sour cherry cultivars (1.4 to 2.7 g), and 39 duke cherry (4.4 to 6.0 g) cultivars from Iran. Similarly, the fruit weight of the sour cherry cultivars, “Oblačinska” and “Cigančica”, were reported as between 3.48 ± 0.11 g and 2.66 ± 0.09 g, respectively [23]. The capuli fruit weight reported in this study was below the average size of the commercial sweet cherry cultivars described above, but it was higher and comparable to the fruit data for the sour cherry and duke cherry cultivars, respectively.

Table 2. Fruit characteristics of *Prunus serotina* subsp. *capuli* genotypes, collected in the Andes region of Ecuador in 2016 and 2019 seasons.

Genotype ID	Fruit Diameter (mm)				Fruit Height (mm)				Ten Fruit Weight (g)				SSC (°Brix)			
	2016		2019		2016		2019		2016		2019		2016		2019	
PserCH101 ^z	13.0	ij ^y	14.4	d-f	12.3	kj	12.2	h	12.8	kl	17.7	gh	20.0	b-f	27.1	a
PserCH108	16.0	c-h	15.5	de	14.6	c-i	14.4	d-g	28.5	d-f	21.3	e-g	25.3	ab	21.5	b-f
PserCH110	15.1	e-j	14.5	d-f	13.7	g-j	12.5	gh	23.0	g-i	21.0	e-g	19.2	d-g	25.5	ab
PserCH113	15.7	c-i	17.0	cd	14.5	d-i	13.5	d-g	24.1	f-i	29.0	cd	14.1	g	24.9	a-c
PserCH132	16.1	b-g	14.4	d-f	14.1	e-j	12.7	f-h	21.8	h-j	21.3	e-g	16.2	e-g	21.6	a-f
PserCH142	15.4	d-j	14.6	d-f	13.3	h-k	13.4	d-h	19.9	h-j	22.0	e-g	27.6	a	23.4	a-d
PserCH94	12.8	j	16.4	c-e	11.4	k	14.7	c-f	11.7	l	22.3	d-g	18.5	d-g	21.8	a-e
PserCO01	15.8	c-h	16.0	c-e	14.6	c-i	13.6	d-h	25.4	e-i	24.0	d-g	19.4	d-g	16.2	f-h
PserCO13	14.0	f-j	12.4	f	13.8	f-j	12.4	gh	15.4	j-l	12.0	h	20.6	b-f	21.5	b-f
PserCO14	15.9	c-g	16.2	c-e	15.5	b-f	13.7	d-h	24.3	e-i	19.0	fg	25.1	a-c	17.2	e-h
PserCO16	13.3	h-j	19.8	ab	12.5	i-k	16.7	bc	19.2	i-k	49.3	a	23.5	a-d	14.3	gh
PserCO21	18.3	a-c	15.1	d-f	15.9	a-f	13.4	d-h	24.7	e-i	27.0	de	17.2	e-g	20.6	b-f
PserCO22	16.6	a-g	16.1	c-e	15.1	c-g	13.0	e-h	29.8	c-f	27.0	de	18.0	d-g	21.4	b-f
PserCO26	14.9	e-j	15.0	d-f	14.7	c-f	14.1	d-h	26.1	e-h	29.0	cd	18.4	d-g	18.2	d-h
PserCO31	16.8	a-f	18.7	bc	16.6	a-d	15.2	b-d	34.6	cd	37.3	b	17.7	e-g	19.5	c-g
PserTU41	17.7	a-e	13.7	ef	16.7	a-c	19.7	a	30.3	c-f	21.0	e-g	19.4	d-g	20.8	b-f
PserTU43	17.9	a-d	15.2	de	17.7	a	13.3	d-h	36.4	bc	20.3	e-g	17.3	e-g	20.0	b-f
PserTU48	18.8	ab	16.4	cd	17.3	ab	17.0	b	43.7	a	33.8	bc	18.5	d-g	17.9	e-h
PserTU53	16.3	b-g	21.7	a	16.2	a-e	19.7	a	30.9	c-e	50.3	a	15.2	fg	19.1	d-g
PserTU57	14.5	f-j	16.3	c-e	13.5	g-k	14.9	b-e	20.4	h-j	26.3	de	21.0	b-e	21.6	a-f
PserTU67	17.9	a-d	16.1	c-e	15.5	b-g	14.0	d-h	33.5	cd	25.3	d-f	23.4	a-d	18.2	d-h
PserTU70	15.7	d-i	16.4	cd	14.6	d-i	14.0	d-h	23.0	g-i	24.3	d-g	18.5	d-g	14.2	gh
PserTU71	14.0	g-j	15.9	de	14.0	f-j	13.5	d-h	19.8	h-j	20.7	e-g	20.1	b-f	19.2	d-g
PserTU77	19.1	a	14.8	d-f	17.5	ab	13.0	f-h	41.4	ab	18.7	f-h	19.6	d-g	13.4	h

^z Genotype: first letter represents the genus (*P* = *Prunus*), next three letters represent the species (*ser* = *serotina*), and the following letters represent the province of origin in Ecuador and collection number (CH101—Chimborazo collection 101). ^y Different letters within a column indicate significant difference between genotypes, using LSD test at $p \leq 0.05$.

The Chimborazo genotypes had the highest average SSC values, with genotypes PserCH142 (27.6 °Brix) in 2016, and PserCH101 (27.1 °Brix) in 2019 (Table 2). The lowest SSC values were 14.1 °Brix (2016) and 13.4 °Brix (2019) for PserCH113 and PserTU77, respectively (Table 2). Vasco et al. [21] studied the average SSC of capuli fruits from Ecuador and reported values between 16.3–22.2 °Brix. Our results are consistent with the research of Vasco et al. [21]. Kappel et al. [26] reported a minimum SSC value of 15 °Brix for sweet cherry cultivars. Khadivi et al. [18] reported the range of TSS (total soluble solids) values of sweet cherries as from 15.6% to 20.88%, sour cherries from 15 to 28%, and duke cherries from 17.13% to 22.53% in Iran. Crisosto et al. [27] studied the importance of TSS, TSS: TA (titratable acidity), and skin color with regard to consumer acceptance for “Bing” and “Brooks” cherry cultivars. The authors pointed out that TSS plays an important role in consumer acceptance. Consumer acceptability is increased with high TSS levels and a minimum 16% was proposed for cherries in the American market. Our study reported average SSC values higher than those reported for sweet cherry, sour cherry, and duke cherry cultivars.

3.2. Endocarp Measurements

In the case of the endocarps' morphological characteristics, the largest endocarp diameter was found in the genotypes PserTU41 and PserTU77 (10.4 mm) in 2016, and PserTU53 (12.2 mm) in 2019 (Table 3) (Figures 2 and 3). The highest endocarp height was reported for PserTU43 (13.6 mm) in 2016, and for PserTU53 (12.2 mm) in 2019 (Table 3). Avendaño-Gómez et al. [22] studied the endocarps of capuli fruits from Tlaxcala, Mexico, under a cultivated management system. The authors observed an endocarp thickness of 0.14 ± 0.04 mm, a seed length of 0.94 ± 0.08 cm, and a seed diameter of 0.78 ± 0.13 cm.

Table 3. Endocarp characteristics of *Prunus serotina* subsp. *capuli* genotypes, collected in the Andes region of Ecuador in 2016 and 2019 seasons.

Genotype ID	Endocarp Diameter (mm)				Endocarp Height (mm)			
	2016		2019		2016		2019	
PserCH101 ^z	8.0	ij ^y	8.0	jk	9.4	h	8.5	j
PserCH108	9.5	b–e	9.0	c–h	10.2	e–h	11.3	a–c
PserCH110	8.3	g–j	8.3	g–j	10.8	b–f	9.7	e–i
PserCH113	8.2	h–j	8.9	c–h	9.7	gh	10.2	d–g
PserCH132	8.9	d–i	8.4	f–k	10.0	e–h	9.5	g–j
PserCH142	9.5	b–e	9.2	c–f	9.9	f–h	10.7	b–e
PserCH94	7.7	j	8.5	e–j	8.1	i	10.2	e–g
PserCO01	9.2	b–f	9.6	bc	10.7	c–g	10.6	b–f
PserCO13	7.7	j	7.5	k	9.7	gh	9.3	g–j
PserCO14	9.0	c–g	8.7	d–j	10.5	d–h	8.7	ij
PserCO16	8.1	ij	10.4	b	10.2	e–h	11.6	ab
PserCO21	8.5	f–j	8.3	f–k	9.4	h	9.5	g–j
PserCO22	8.6	e–i	8.0	i–k	9.7	f–h	9.3	g–j
PserCO26	8.9	d–i	9.2	c–g	9.9	f–h	9.9	d–g
PserCO31	9.5	a–d	9.3	c–e	11.8	b	9.3	g–j
PserTU41	10.4	a	10.4	b	11.7	bc	9.9	d–g
PserTU43	9.8	a–c	7.6	k	13.6	a	8.7	ij
PserTU48	10.1	ab	10.4	b	11.1	b–e	10.8	b–d
PserTU53	9.1	c–g	12.2	a	11.6	b–d	12.2	a
PserTU57	8.6	e–i	8.9	c–i	9.7	gh	9.6	f–j
PserTU67	9.2	b–f	9.0	c–h	10.3	e–h	10.2	d–g
PserTU70	9.3	b–f	9.2	c–f	9.4	h	10.2	c–g
PserTU71	8.7	d–i	9.4	cd	10.6	d–g	9.5	f–j
PserTU77	10.4	a	8.2	h–k	11.9	b	9.0	h–j

^z Genotype: first letter represents the genus (*P* = *Prunus*), next three letters represent the species (*ser* = *serotina*), and the following letters represent the province of origin in Ecuador and collection number (CH101—Chimborazo collection 101). ^y Different letters within a column indicate significant difference between genotypes, using LSD test at $p \leq 0.05$.

In other *Prunus* species, Khadivi et al. [18] studied Iranian sweet, sour, and duke cherries. The stone lengths ranged from 10.57 to 12.40 mm (sweet cherries), 7.73 to 10.18 mm (sour cherries), and 9.26 to 11.78 mm (duke cherries); whereas the stone widths ranged from 8.50 to 10.35 mm (sweet cherries), 8.94 to 10.51 mm (duke cherries), and 7.17 to 10.30 mm (sour cherries). The endocarp data collected in our research are comparable to the endocarp data collected for capuli from Mexico and other cherries.

The overall means for all the variables within a year were calculated separately, according to their province of origin (Table 4). Significant differences were present across the different provinces, while comparing the overall means for the variable fruit height and endocarp diameter for both years. The SSC values were the highest for Chimborazo province genotypes for the year 2019 but no significant differences among the provinces were observed for the year 2016. The ten fruit weight was significantly higher for the Tungurahua genotypes for the year 2016. No significant differences were present among the provinces for the ten fruit weight for the year 2019. The fruit diameter and endocarp height were significantly higher for Tungurahua, in comparison to the other provinces in 2016, but no significant differences were present across provinces for the year 2019.

Table 4. Fruit and endocarp characteristics of *P. serotina* subsp. *capuli*, according to its provinces of origin in Ecuador.

Year	Province	Fruit Diameter (mm)	Fruit Height (mm)	Ten Fruit Weight (g)	Endocarp Diameter (mm)	Endocarp Height (mm)	SSC (°Brix)
2016	Chimborazo	14.9 b ^z	13.4 c	20.3 b	8.6 b	9.7 b	20.1 a
	Cotopaxi	15.7 b	14.8 b	24.9 b	8.7 b	10.2 b	20.0 a
	Tungurahua	16.9 a	15.9 a	31.1 a	9.5 a	11.1 a	19.2 a
2019	Chimborazo	15.3 a	13.3 b	22.1 a	8.6 b	10.0 a	23.7 a
	Cotopaxi	16.2 a	14.0 b	28.1 a	8.9 b	9.8 a	18.6 b
	Tungurahua	16.3 a	15.5 a	27.5 a	9.5 a	10.0 a	18.2 b

^z Different letters within a column and within a year indicate significant difference between genotypes, using LSD test at $p \leq 0.05$.

In the current study, fruit collected from the wild in Ecuador comprised a large variation in fruit diameter, fruit height, fruit weight, SSC, endocarp diameter, and endocarp height (Tables 2–4). This phenotypic variation present in the wild Ecuadorian capuli fruit can be used as a foundation for the future capuli breeding programs. *Prunus serotina*, in North America, is mostly used for furniture purposes, but its fruit lacks flavor and size, which are important commercial fruit attributes. The best forms of capuli fruits are found in Ecuador [8]. Although capuli fruit is important to the Ecuadorian people, no commercial varieties of capuli fruits are available in the Ecuadorian market. In Mexico, the seeds of the capuli fruit are also used as snacks, in addition to eating fresh or dried fruit, or making other products [28]. Capuli fruit holds the potential for being a multipurpose commercial product, where both the fruit and seeds can be utilized for different purposes.

3.3. Multivariate Analyses for 2016 and 2019

The edible portions in cherries are the epicarp and mesocarp, i.e., the skin and flesh of the fruit. Beneath these, there is the stony endocarp, which is inedible [29]. In the case of sweet cherries, consumers prefer cherries with a small endocarp and a large quantity of fruit pulp [24]. This study focused on characterizing the fruit and endocarp variables and their relationships.

The results of the multivariate analyses are shown in Tables 5 and 6, for the years 2016 and 2019, respectively. A strong positive correlation was found between the fruit weight and diameter within both years ($r_{\text{fruitwt vs fruitdia 2016,2019}} = 0.89$, $p \leq 0.0001$). Likewise, the fruit diameter and endocarp diameter were positively correlated for both years ($r_{\text{fruitdia vs endocarpdia 2016}} = 0.78$, $r_{\text{fruitdia vs endocarpdia 2019}} = 0.79$; $p \leq 0.0001$). The endocarp height and fruit height were positively correlated ($r_{\text{fruitht vs endocarpht 2016}} = 0.78$, $r_{\text{fruitht vs endocarpht 2019}} = 0.61$; $p \leq 0.05$). All fruit and endocarp size characteristics were positively correlated with each other within a season. SSC was not correlated with any of the size variables for the fruits or endocarps in both years (Tables 5 and 6). Large-fruited capuli genotypes were consistently characterized by a large endocarp. This will make the selection for a large-fruited and small endocarp genotype difficult. On the other hand, the selection for a high SSC can be made independently of other variables.

Other studies have reported the presence of a positive correlation between the fruit and endocarp size variables. Rakonjac et al. [30] reported that all the fruit size variables in “Oblačinska” sour cherry accessions were positively related to each other. Demirsoy and Demirsoy [31] also found a positive polynomial relationship between fruit weight and fruit diameter in sweet cherries. Khadivi-Khub [32] found a positive correlation between fruit weight vs. stone weight, fruit weight vs. fruit length, and fruit width vs. fruit diameter when evaluating 70 cherry genotypes. In addition, significant negative correlations between the TSS vs. fruit were reported in cherry genotypes by Khadivi et al. [18].

Table 5. Multivariate analysis of fruit and endocarp characteristics of *Prunus serotina* subsp. *capuli* genotypes, collected in the Andes region of Ecuador in 2016.

	Ten Fruit Weight (g)	Fruit Diameter (mm)	Fruit Height (mm)	SSC (°Brix)	Endocarp Diameter (mm)	Endocarp Height (mm)
Ten fruit weight (g)	1.00 ^x <0.0001 ^y					
Fruit diameter (mm)	0.89 <0.0001	1.00 <0.0001				
Fruit height (mm)	0.92 <0.0001	0.92 <0.0001	1.00 <0.0001			
SSC (°Brix)	−0.18 0.4068	−0.19 0.3848	−0.27 0.1968	1.00 <0.0001		
Endocarp diameter (mm)	0.82 <0.0001	0.78 <0.0001	0.79 <0.0001	0.08 0.7181	1.00 <0.0001	
Endocarp height (mm)	0.73 <0.0001	0.59 0.0023	0.78 <0.0001	−0.14 0.517	0.70 0.0001	1.00 <0.0001

^x Correlation coefficient *r*; ^y *p*-value.**Table 6.** Multivariate analysis of fruit and endocarp characteristics of *Prunus serotina* subsp. *capuli* genotypes, collected in the Andes region of Ecuador in 2019.

	Ten fruit Weight (g)	Fruit Diameter (mm)	Fruit Height (mm)	SSC (°Brix)	Endocarp Diameter (mm)	Endocarp Height (mm)
Ten fruit weight (g)	1.00 ^x <0.0001 ^y					
Fruit diameter (mm)	0.89 <0.0001	1.00 <0.0001				
Fruit height (mm)	0.66 0.0004	0.82 <0.0001	1.00 <0.0001			
SSC (°Brix)	−0.30 0.1486	−0.32 0.1234	−0.27 0.1953	1.00 <0.0001		
Endocarp diameter (mm)	0.76 <0.0001	0.79 <0.0001	0.85 <0.0001	−0.32 0.1305	1.00 <0.0001	
Endocarp height (mm)	0.69 0.0002	0.61 0.0016	0.61 0.0014	−0.23 0.2747	0.78 <0.0001	1.00 <0.0001

^x Correlation coefficient *r*; ^y *p*-value.

3.4. Principal Component Analysis (PCA)

A principal component analysis aims to reduce the number of parameters to differentiate the relationships between variables and genotypes. This technique helps in dividing the original variables in the dataset into smaller groups. The groups in a PCA are not related to each other, except the variables within each group [33]. The results from the PCA conducted in this study identified that PC1 and PC2 components accounted for 83.7% of the total variation in the studied variables for *P. serotina* subsp. *capuli* (Table 7).

Table 7. Eigenvectors and proportion of the total variability for each principal component axes for fruit and endocarp characteristics of *Prunus serotina* subsp. *capuli* genotypes, collected in the Andes region of Ecuador in 2016 and 2019.

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Ten fruit wt	0.45446	0.04332	−0.24181	0.64872	−0.11152	−0.54758
SSC (°Brix)	−0.15948	0.97704	−0.07358	0.02714	0.11666	−0.01418
Fruit dia (mm)	0.45266	0.01889	−0.50161	0.11916	0.20149	0.69881
Fruit ht (mm)	0.45598	0.01321	−0.02192	−0.55327	0.58087	−0.3846
Endocarp dia (mm)	0.44599	0.17733	0.01862	−0.43673	−0.76052	0.01344
Endocarp ht (mm)	0.39536	0.10743	0.82685	0.25959	0.13253	0.25204
Total Eigenvalue	4.0911	0.9329	0.4765	0.2483	0.1892	0.0621
Variance %	68.184	15.549	7.941	4.138	3.153	1.035
Cumulative %	68.184	83.734	91.675	95.812	98.965	100

In PC1, the variables with the highest factor loadings were the ten fruit weight, the fruit diameter, the fruit height, and the endocarp diameter and height. In the SSC, °Brix had the highest factor loadings. These results are confirmed in Figure 4, where the SSC variable is observed on a different quadrant from all the other variables.

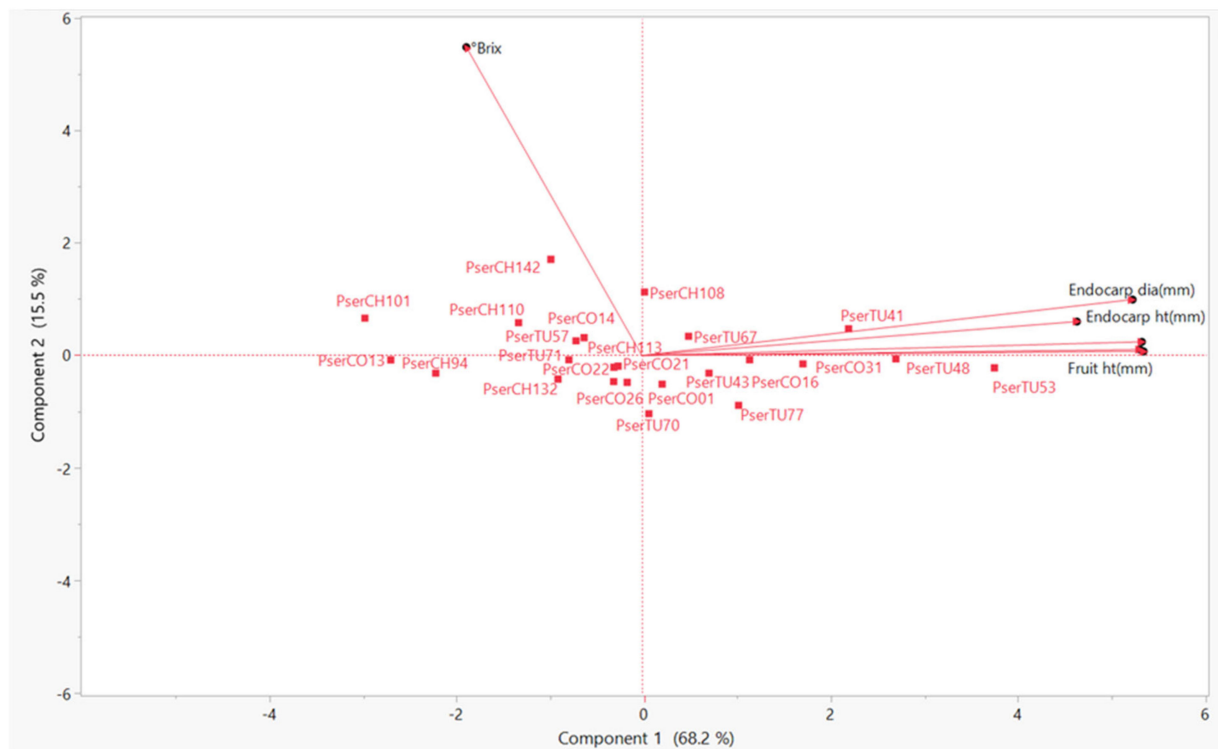


Figure 4. Principal component analysis (PCA) based on the fruit and endocarp characteristics of *Prunus serotina* subsp. *capuli* genotypes, collected in the Andes region of Ecuador in 2016 and 2019.

The genotypes with the highest PC1 scores were those with overall high values for fruit and endocarp variables, such as PserTU48 and PserTU53. Whereas, the genotypes with high PC2 scores are the ones with high SSC values, such as the genotypes PserCH142, PserCH110, and PserCH108. No clear-cut groups were observed according to their province of origin in the PCA, based on the morphological characteristics studied (Figure 4).

The results suggest that there is morphological variation in the genotypes from Chimborazo, Cotopaxi, and Tungurahua. However, these differences did not result in separate groupings, as related to their province of origin. Guadalupe et al. [34], while studying the genetic diversity and population structure of capuli from eight Ecuadorian provinces, reported the lack of clear population differentiation among the capuli from the different provinces. They proposed the reason for the diversification of Ecuadorian capuli could be outcrossing and self-incompatibility.

4. Conclusions

The results of this study can be used as a reference for *P. serotina* subsp. *capuli*. In addition, the information presented is important for future capuli breeding and management programs in Ecuador and the US. The present study shows the feasibility and the great potential in selecting and further breeding capuli fruit with superior commercial characteristics. The breeding and selection of a large-fruited capuli with a high °Brix should be attainable, based on our study. Superior genotypes for fruit size and weight, such as PserTU48 and PserTU53, could be used for breeding and selection to obtain a large-fruited capuli. On the other hand, the genotypes PserCH142, PserCH110, and PserCH108 could be used to obtain a high SSC-fruited capuli. The material studied in this research was col-

lected in the wild, without any advanced breeding, selection, or commercial management. Capuli fruit holds plenty of commercial potential in Ecuador and could be an interesting species to be evaluated in the US. Capuli fruit has a promising future, similar to other stone fruits. Future research will include adaptation to the south-eastern US. Open-pollinated seeds from a wide collection of individual fruits will be germinated and grown for further evaluation and selection.

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