Multivariate analysis in the characterization of feijoa fruits (*Acca sellowiana* [O. Berg] Burret) in Tungurahua, Ecuador

Análisis multivariante en la caracterización de frutos de la feijoa (*Acca sellowiana* [O. Berg] Burret) en Tungurahua, Ecuador

Análise multivariada na caracterização de frutos de feijoa (*Acca sellowiana* [O. Berg] Burret) em Tungurahua, Equador

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Abstract

The feijoa (*Acca sellowiana* [O. Berg] Burret) is a Myrtaceae native to southern Brazil and northern Uruguay. Its fruits can be consumed fresh or processed into juice, ice cream, wine, liqueurs and others. In Ecuador, feijoa cultivation has been reported since 1980 in the province of Tungurahua. To evaluate the morphological and physicochemical characteristics of feijoa fruits through multivariate analysis, fruits from 18 farms located in Tungurahua, Ecuador were analyzed. A sample of 10 fruits per farm were analyzed in the food processing laboratory of the Tungurahua Higher Technological Institute. Descriptive statistics and multivariate analysis were employed for data evaluation. The fruits exhibited an oboval shape with erect sepals, moderate skin roughness, and white pulp. Fruit diameter ranged from 2.0 to 5.1 cm (CV=17 %), and fruit length ranged from 2.46 to 10.1 cm (CV=16.2 %), indicating variability in fruit size. Fruit biomass ranged from 8 to 133 g, with pulp yields between 4.6 % and 46.2 %. Total soluble solids ranged from 8.0 to 20 °Brix; the pH and titratable acidity (citric acid percentege) averaged 3.5 and 0.50, respectively. Fruit length and diameter showed a high correlation with fruit biomass. PCA identified the formation of three groups of producers, based on fruit size.

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Resumen

La feijoa (*Acca sellowiana* [O. Berg] Burret) es una mirtácea nativa del sur de Brasil y norte de Uruguay, sus frutos pueden ser consumidos *in natura* o procesados como jugo, helados, vinos, licor, entre otros. En Ecuador desde 1980, se reportan cultivos de feijoa en la provincia de Tungurahua. Con el objetivo de evaluar las características morfológicas y físico-químicas de los frutos de feijoa mediante análisis multivariante, se evaluaron frutos provenientes de 18 fincas ubicadas en Tungurahua, Ecuador. Una muestra de 10 frutos por cada finca se analizaron en el laboratorio de procesamiento de alimentos del Instituto Superior Tecnológico Tungurahua. Para el análisis de los datos se emplearon estadísticas descriptivas y análisis multivariante. Los frutos mostraron un forma oboval con sépalos erectos, rugosidad moderada en la piel del fruto y pulpa de color blanco. El diámetro del fruto varió de 2,0 a 5,1 cm, (CV= 17 %), con longitud del fruto de 2,46 a 10,1 cm (CV= 16,2 %) mostrando variabilidad en el tamaño de las frutas. La biomasa del fruto estuvo entre 8 y 133 g, con rendimientos de pulpa entre 4,6 y 46,2 %. Los sólidos solubles totales estuvieron entre 8,0 a 20 ºBrix; el pH y la acidez titulable (porcentaje de ácido cítrico) fueron en promedio 3,5 y 0,50, respectivamente. La longitud y el diámetro del fruto presentaron una alta correlación con la biomasa del fruto. El PCA mostró la formación de tres grupos de productores, en función del tamaño de los frutos.

Palabras clave: Patate, guayabo del país, goiabeira serrana, PCA.

Resumo

A feijoa (*Acca sellowiana* [O. Berg] Burret) é uma myrtaceae, nativa do sul do Brasil e norte do Uruguai. Seus frutos podem ser consumidos in natura ou processados como sucos, sorvetes, vinhos, licores, entre outros. No Equador, desde 1980 há registros de cultivos de feijoa na província de Tungurahua. Com o objetivo de avaliar as características morfológicas e físico-químicas dos frutos de feijoa mediante a análise multivariada, foram avaliados frutos provenientes de 18 propriedades localizadas em Tungurahua, Equador. Uma amostra de 10 frutos por propriedade foi avaliada no laboratório de processamento de alimentos do Instituto Superior Tecnológico Tungurahua. Para a análise dos dados, foram utilizadas estatísticas descritivas e análise multivariada. Os frutos apresentaram formato oboval, com sépalas eretas, rugosidade moderada na casca e polpa de cor branca. O diâmetro dos frutos variou de 2,0 a 5,1 cm (CV=17 %), com comprimento dos frutos variando de 2,46 a 10,1 cm (CV=16,2 %), indicando variabilidade no tamanho dos frutos. A biomassa dos frutos ficou entre 8 e 133 g, com rendimentos de polpa variando entre 4,6 % e 46,2 %. Os sólidos solúveis totais variaram de 8,0 a 20 °Brix; o pH e a acidez titulável (porcentagem de ácido cítrico) foram em média 3,5 e 0,50, respectivamente. O comprimento e o diâmetro dos frutos apresentaram alta correlação com a biomassa dos frutos. PCA identificou três grupos de produtores com base no tamanho dos frutos.

Palavras-chave: Patate, goiabeira-serrana, guayabo del país, PCA.

Introduction

Feijoa (*Acca sellowiana* [O. Berg] Burret) is a myrtacea native to southern Brazil and Uruguay, with the possibility of natural dispersal in Argentina (Keller and Tressens, 2007; Nuñez *et al*., 2023). In the center of origin and diversity it is popularly known as goiaba-do-mato, goiabeira-serrana or guayabo del país (Puppo *et al*., 2014; Donazzolo *et al*., 2017) and in countries where it is exotic it is known as feijoa, guayabo de Brasil, pineapple-guava, guavasten (Parra-Coronado *et al*., 2015). Due to its adaptability to different environments it is commercially cultivated in New Zealand, Colombia and California (USA), to a lesser extent in Brazil and in a dozen countries (Zhu, 2018; Sánchez-Mora *et al*., 2020; Vatrano *et al*., 2022).

Feijoa is a predominantly allogamous species with hermaphrodite flowers that presents barriers to self-fertilization such as dichogamy by protogyny and self-incompatibility (Finatto *et al*., 2011); self-compatible and self-incompatible genotypes are reported in Brazilian germplasm and cultivars distributed throughout the world (Sánchez-Mora *et al*., 2022). This temperate climate species requires cold hours to produce fruits, in temperate or subtropical regions, plants accumulate cold in winter to sprout, flower and fruit, while in the Andean region they do it continuously due to the continuity of low temperatures (Sánchez-Mora *et al*., 2020). In countries where feijoa is exotic, it is planted in high regions to accumulate cold hours, for example, in Colombia, in the Department of Cundinamarca, cultivation has been reported at altitudes of 1,800 to 2,580 m.a.s.l. (Parra-Coronado *et al*., 2015), in Mexico, state of Veracruz, feijoa cultivation has been recorded in mountainous regions above 1,300 m.a.s.l. (González-García *et al*., 2018).

Brazil and Uruguay type genotypes are recognized in feijoa, which differ in their distinctive characteristics in fruits, seeds and leaves, as well as in their geographic distribution pattern (Rivas *et al*., 2024). Several studies showed that fruits of the Uruguay type were smaller in size and presented greater pericarp thickness (Nodari *et al*., 1977; Amarante *et al*., 2008). For example, Borsuk *et al*. (2017) studying 18 natural populations of feijoa in southern Brazil, found two Uruguay type populations (QLCG and QLPT) that differed in several characteristics, with emphasis on lower total fruit, pericarp and pulp biomass, where only total soluble solids values were higher in Uruguay type plants.

Feijoa fruits stand out for their high biological value due to the presence of β-carotene, R-active agents, vitamin C and B5, polyphenols (flavones), dietary fiber, minerals (such as potassium), as well as for presenting a broad spectrum of antimicrobial activity, which is why they can be considered as potential raw material for the food and nutraceutical industry (Belous *et al*., 2014; Zhu, 2018; Phan *et al*., 2019). All parts of the feijoa plant exhibit effective antioxidant activity (between 81.5 and 91.3 %); however, peel extracts have slightly higher antioxidant activity compared to leaf and pulp extracts (Karslı, 2021).

Feijoa fruit peel has potential for the extraction of functional ingredients (polyphenols and pectins), while other parts of the plant, such as leaves and shoots, contain relevant bioactive compounds, including polyphenols (phenolic acids and flavonoids) and non-starch polysaccharides such as pectin (Zhu, 2018). In the study of Sganzerla *et al*. (2020), feijoa peel presented the highest content of ash, lipids, proteins, carbohydrates, phenolic compounds and antioxidant activity compared to feijoa pulp. The peel flour is rich in dietary fiber (45-48 %) and the predominant monosaccharides include glucose (34-43 %) and xylose (33-37 %), followed by uronic acid (9-12 %) (Almeida *et al*., 2020; Cimmino *et al*., 2022).

Multivariate analysis examines the interrelationships between multiple variables simultaneously, which is fundamental to understand complex data where these variables interact and influence

the results; this approach allows exploring patterns, relationships or structures that are not evident to the naked eye, and can be applied to metric, categorical or mixed data (Bartholomew, 2010). Different multivariate techniques, such as cluster analysis, principal component analysis, factor analysis, discriminant analysis, among others, have been used for the characterization of feijoa fruits, for the identification of replicates and quantification of genetic divergence (Saifert *et al*., 2020; Sganzerla *et al*., 2020; Citadin *et al*., 2022).

In Ecuador, feijoa is still produced on a small scale and for ornamental purposes. The regions where feijoa is grown are Pichincha (Guayllabamba), Tungurahua (Patate) and Azuay (Chilcapamba). However, there are few studies of feijoa, highlighting the one conducted by Vilatuña *et al*. (2016) who report it as a host of fruit flies. Thus, the objective of this study was to analyze the morphological and physicochemical characteristics of feijoa fruits present in the farms of producers in the Province of Tungurahua, through multivariate analysis, in order to establish its potential as a crop alternative in Ecuador.

Materials and methods

Location of the trial

It is estimated that feijoa was introduced in the province of Tungurahua, Ecuador in the 1980s by seed multiplication. During the months of February-April 2023, 18 feijoa producing farms were evaluated in the province of Tungurahua, Ecuador, located in the parishes of Patate (14 farms) and Los Andes (3 farms) of the canton San Cristobal de Patate and in the parish Juan Montalvo (1 farm) of the canton Ambato at an altitude ranging from 2,065 to 2,904 m.a.s.l. (Figure 1A).

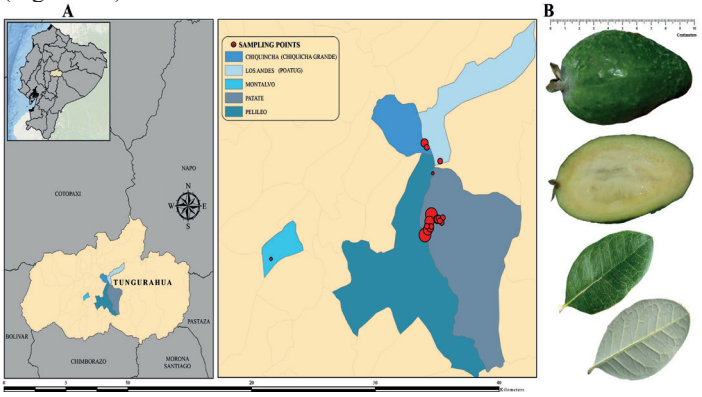

Figure 1. Feijoa cultivation in Tungurahua, Ecuador. A) Spatial distribution of the sampled farms linked to feijoa production; B) Characteristics of feijoa fruits and leaves.

For the selection of the farms, all the properties located in the province of Tungurahua were considered in which the presence of feijoa trees older than five years was reported, whose average heights were between 3 and 5 m. The abaxial side of the leaves in all the trees was white with pubescence, characteristic of the Uruguay type tree (Figure 1B). The farms presented different levels of agronomic management, from those with basic practices (fertilization, pruning and irrigation) to those with complete management, including sanitary pest control.

Plant material

Trees with the best sanitary and productive characteristics at the time of fruit collection were selected and numbered in order of visits. A sample of 10 fruits was obtained from each farm, when they presented physiological maturity (when the fruits detach easily from the plant). The samples were taken to the food processing laboratory of the Instituto Superior Tecnológico Tungurahua (ISTT) for processing.

Determination of feijoa fruit characteristics

Qualitative characteristics of the fruit were determined: fruit shape, sepal insertion, roughness, skin color and fruit pulp (Ministério da Agricultura e Pecuária [MAPA], 2020). In addition, the physicochemical characteristics: fruit diameter (cm), fruit length (cm) and pericarp thickness (cm) were evaluated using a digital calibrator (Mitutoyo mt531, Japan). Fruit biomass (g), pericarp (g) and pulp (g) were estimated with a digital balance (Mettler Toledo model JL6001GE/A, sensitivity 0.1 g, USA). According to MAPA (2020), pericarp thickness is the maximum width from the edge of the locule to the skin; and fruit pulp corresponds to the locules and the core of the fruit. Pulp yield (%) was estimated by the ratio of pulp to fruit biomass. Total soluble solids (TSS) were measured with a portable refractometer (Zuzi model ATC model SK-RF012, 0 to 20 % °Brix, China). To quantify the titratable acidity (TA, percentage of citric acid), a mini titrator (Hanna model HI84532, USA) was used, starting from 5 mL of juice extracted from the sample of the 10 fruits, which was diluted in 20 mL of distilled water; this solution was titrated with NaOH (≥97.0 %, Fisher Scientific) at 0.1 N, until reaching pH 8.2. The results were expressed as percent citric acid. The pH of the sample was determined prior to titration.

Statistical analysis

For data analysis, a mixed matrix was prepared with qualitative and quantitative data, with which descriptive statistics were performed. Spearman's correlation ($p<0.05$), heat map and principal component analysis were determined with the quantitative data, using the free software R Development Core Team (2024).

Results and discussion

According to the MAPA (2020) descriptors, in the province of Tungurahua, the 18 farms were characterized by having obovate fruits, erect sepals and white flesh. In 94 % of the farms evaluated, the fruits presented moderate roughness in the skin. On the other hand, the color of the fruit skin showed greater variation, with 28 % of the farms showing light green fruit, 22 % medium green fruit and 50 % dark green fruit (Figure 1B).

The fruit biomass variable showed the greatest variation (CV= 73.1 %), while the fruit diameter and length variables showed the least variation (CV= 15.9 %) (Table 1). Fruit diameter varied from 2 (farm F16) to 5.1 cm (farm F7) and from 3.5 (farm F10) to 10.1 cm (farm F6) in length. Fruit biomass ranged from 8 (farm F18) to 133 g (farm F7), showing different sizes (Table 1; Figure 2A).

Farms F7, F1, F11, F2 and F15 recorded the largest diameter (3.6 ± 0.29 cm), length (7.1 ± 0.37 cm) and fruit biomass (103.8 ± 4.77 g), while farm F16 recorded the smallest diameter (2.53 cm), length (5.14 cm) and fruit biomass (12.6 g) (Table 1). This shows that these variables are strongly related (Figure 2A). The variables length, diameter, fruit biomass and pulp biomass (to estimate yield) were the main variables used to differentiate fruits (Puppo *et al*., 2014).

The values of fruit diameter and length found in Tungurahua were lower than those reported for Brazilian-type feijoa fruits and similar to those reported for the Uruguay type and in countries where feijoa is exotic.

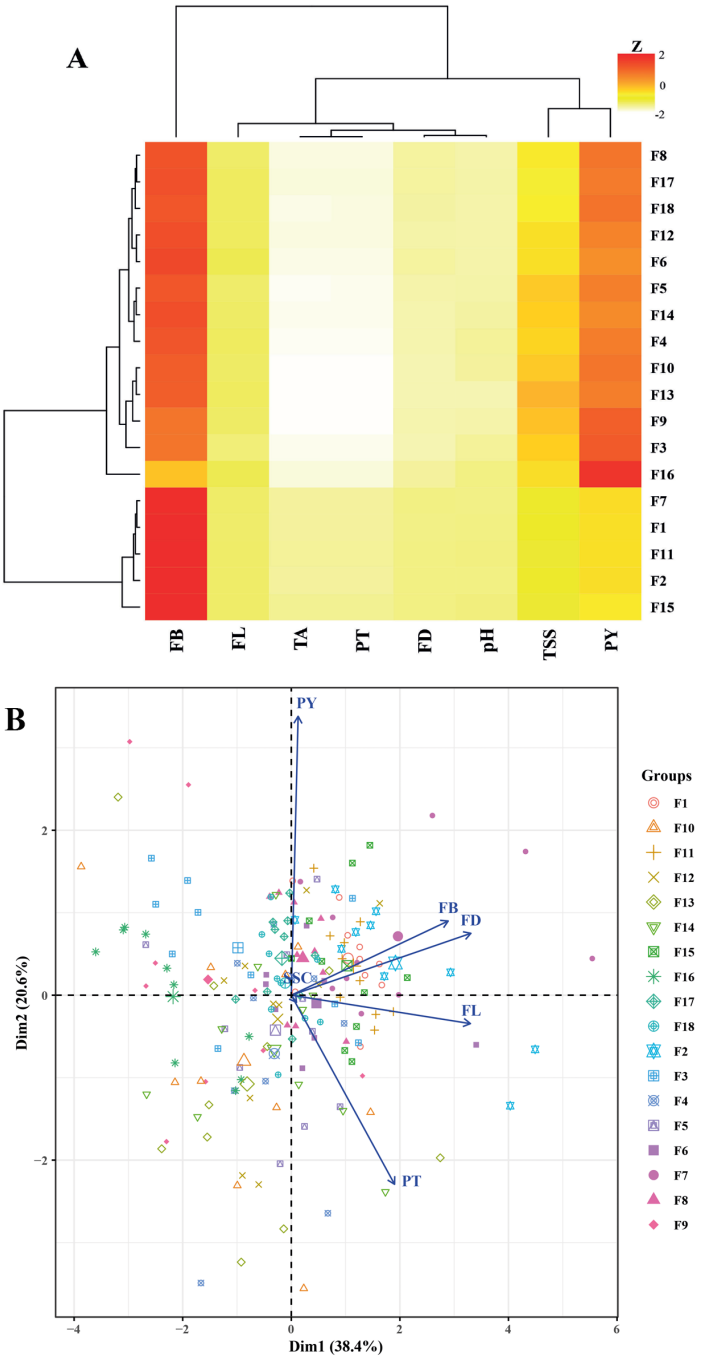

Figure 2. Multivariate analysis of physicochemical characteristics of fruit from 18 feijoa producing farms: A) Heatmap of physicochemical characteristics of fruit; B) Principal component analysis, of the variables: fruit biomass (FB, g), pericarp thickness (PT, cm), fruit diameter (FD, cm), fruit length (FL, cm), pulp yield (PY, %), total soluble solids (TSS, °Brix), titratable acidity (AT citric acid, %) and pH.

In fruits of the Brazil type, different ranges in fruit diameter and fruit length have been recorded, for example: In Rio Grande do Sul, Donazzolo *et al*. (2017) reported fruit diameters from 1.7 to 7.1 cm, and fruit length from 2.4 to 9.6 cm; while in Santa Catarina (São Joaquim) Sanchez-Mora *et al*. (2019), reported values from 3.4 to 6.4 cm in diameter and values from 4.0 to 9.6 cm, in fruit length. In fruits of the Uruguay type, Rivas *et al*. (2024) reported fruit diameters of 1.2 to 4.2 cm and fruit length of 1.6 to 5.3 cm. Borsuk *et al*. (2017), evaluated 18 natural populations from southern Brazil (Paraná, Santa Catarina and Rio Grande do Sul) and found two populations with Uruguay-type characteristics (QLCG and QLPT) that recorded lower values in fruit diameter from 1.9 to 3.1 cm and from 2.4 to 6.9 cm in fruit length.

In countries where feijoa is exotic, lower values of diameter and fruit length are presented. For example, in Colombia, Parra-Coronado *et al*. (2015) recorded values of 3.5 to 4.9 cm in diameter and 5.7 to 7.5 cm in fruit length. In Mexico, González-García *et al*. (2018) obtained fruit diameters of 3.1 to 4.0 cm, and fruit length of 5.1 to 5.6 cm. In Turkey, Beyhan *et al*. (2011) reported fruit diameters ranging from 2.3 to 3.9 cm and lengths varying from 2.8 to 6.0 cm. In Italy, in the evaluation of different commercial cultivars, ranges of 4.3 to 5.1 in diameter and 5 to 7.2 cm in fruit length were observed (Pasquariello *et al*., 2015). Zhao *et al*. (2023) found in New Zealand cultivars fruit length from 6.6 cm (Pounamu) to 10.2 cm (Kaiteri), with fruit diameter ranging from 4.5 cm (Apollo) to 7.4 cm (Unique).

Feijoa in Tungurahua presented a smaller range in fruit biomass (Table 1) with respect to those reported in fruits from Brazil, in which values from 6 to 209 g have been recorded (Nodari *et al*., 1977; Donazzolo *et al*., 2017; Sánchez-Mora *et al*., 2019). In Uruguay and in several countries where feijoa is exotic, fruit sizes similar to those of Tungurahua have been reported, such as those indicated by Rivas *et al*. (2024) in Uruguay-type feijoa fruits (1.9 to 51.8 g). In Mexico, González-García *et al*. (2018), have reported fruit biomasses ranging from 29.5 to 50.3 g and in Turkey, Beyhan *et al*. (2011) found fruit biomasses ranging from 18.6 to 40 g. However, fruit sizes evaluated in Tungurahua, did not differ from those reported in commercial cultivars, for example: in Brazilian commercial cultivars fruit biomass has ranged from 94 to 150 g for the cultivars SCS411 Alcântara and SCS414 Mattos, respectively (Santos *et al*., 2022). In the department of Cundinamarca (Colombia), fruit biomasses of 30.5 to 98.9 g have been reported with the cultivar 'Quimba' (Parra-Coronado *et al*., 2015). This highlights the potential of Ecuadorian feijoa germplasm for future applications in agricultural production and genetic improvement.

One of the desirable characteristics of feijoa fruit is pulp yield. In the farms evaluated, this variable ranged from 4.6 to 46.2 % in F4 and F9, respectively. In farms F3 and F8 the average fruit pulp yield was above 30 % (Table 1; Figure 2A). In Brazil, feijoa fruits have ranged from 5.5 to 53.8 % in pulp yield (Borsuk *et al*., 2017; Sánchez-Mora *et al*., 2019). Higher pulp yields have been reported in Uruguay-type feijoa by Rivas *et al*. (2014), in fruits from Uruguayan populations (11.7 to 68.8 %).

Pericarp thickness ranged from 0.3 to 0.8 cm in F3, F7 and F13, respectively; with an average of 0.5 cm (Table 1; Figure 2A). This characteristic is of agronomic importance because it is the opposite of pulp yield, so it is desired that the pericarp thickness of the fruit be less thick to obtain higher pulp yield. These variations were similar to those found by Silveira *et al*. (2015) and Rivas *et al*. (2024), who reported values from 0.11 to 0.69 cm in pericarp thickness of fruits from different genetic selections of Uruguay type feijoa. Brazil type fruits, reported higher pericarp thickness with an average of 0.8 cm varying from 0.4 to 1.5 cm (Sanchez-Mora *et al*., 2019). Likewise, Borsuk *et al*. (2017), studying feijoa populations in southern Brazil reported a greater amplitude of pericarp thickness (0.2 to 1.6 cm). This variable is a discriminant descriptor in the selection of feijoa accessions (Puppo *et al*., 2014).

Table 1. Descriptive analysis of the physical-chemical characteristics of the fruit in 18 feijoa producing farms. Tungurahua, Ecuador.

Variables	Descriptive parameters	Farms																		Total
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	
Fruit diameter (cm)	Average	3.4	3.9	3.0	3.1	3.3	3.5	3.8	3.6	2.9	3.0	3.4	3.1	2.9	3.1	3.3	2.5	3.4	3.3	3.2
	Minimum	2.9	3.0	2.5	2.6	2.5	2.9	3.1	2.9	2.2	2.5	3.0	2.6	2.3	2.4	2.9	2.0	3.0	2.9	2.0
	Maximum	3.9	4.8	3.6	3.7	3.8	3.9	5.1	3.9	4.1	3.6	3.8	4.2	4.1	3.7	3.8	2.8	3.7	3.6	5.1
	CV (%)	10.5	13.7	12.9	9.4	12.0	7.6	19.0	8.6	20.1	13.6	8.5	14.1	19.1	13.7	11.7	9.4	6.6	8.2	15.9
Fruit length (cm)	Average	6.9	7.3	5.9	6.5	6.3	7.4	7.7	6.7	5.6	6.1	6.9	6.7	6.1	6.6	6.9	5.1	6.7	6.7	6.6
	Minimum	6.3	6.4	4.1	4.4	4.2	6.6	6.3	6.3	3.9	3.5	6.5	5.7	4.0	5.0	6.6	4.0	6.2	6.3	3.5
	Maximum	7.4	8.7	7.8	7.3	7.4	10.1	9.9	7.2	6.8	8.2	7.5	7.5	7.9	7.9	7.3	6.5	7.2	7.3	10.1
	CV (%)	6.1	12.0	21.8	14.1	16.2	15.6	18.0	4.5	18.3	21.2	4.9	9.0	18.2	14.5	3.6	19.6	4.8	4.7	15.9
Fruit biomass (g)	Average	103.0	99.0	28.2	30.4	32.4	33.4	102.6	36.3	22.2	26.8	102.4	35.9	26.4	33.9	111.8	12.6	36.1	33.6	50.7
	Minimum	77.0	68.0	9.0	10.0	16.0	14.0	71.0	18.0	10.0	14.0	71.0	21.0	12.0	11.0	91.0	8.0	11.0	16.0	8.0
	Maximum	127.0	119.0	68.0	59.0	55.0	66.0	133.0	53.0	55.0	59.0	122.0	60.0	61.0	58.0	130.0	19.0	55.0	53.0	133.0
	CV (%)	16.4	17.9	73.9	52.5	38.9	58.6	23.6	34.4	60.2	58.2	18.9	40.9	59.2	43.8	11.7	27.5	38.7	36.0	73.1
Pulp yield (%)	Average	28.5	28.2	32.3	25.0	26.2	27.8	29.8	30.2	28.0	23.7	28.6	26.8	22.6	24.2	27.8	28.4	28.6	29.2	27.5
	Minimum	25.0	24.5	27.3	4.6	16.1	25.0	25.0	26.8	12.5	11.1	25.0	12.0	11.8	16.7	25.0	25.0	25.0	25.0	4.6
	Maximum	31.9	33.0	40.0	33.0	37.2	31.9	33.3	33.0	46.2	35.7	31.0	38.3	38.5	30.9	33.0	32.0	33.0	33.0	46.2
	CV (%)	8.0	9.8	11.4	36.7	22.1	9.0	10.0	7.2	37.2	34.2	8.6	31.0	37.3	21.3	10.4	9.0	8.4	9.2	20.7
Pericarp thickness (cm)	Average	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Minimum	0.4	0.4	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.3
	Maximum	0.6	0.8	0.7	0.6	0.7	0.7	0.7	0.6	0.6	0.7	0.6	0.7	0.8	0.7	0.7	0.6	0.6	0.6	0.8
	CV (%)	18.3	26.8	22.9	13.7	12.9	23.2	23.5	19.1	19.4	15.6	15.2	15.1	25.3	19.1	22.1	20.4	15.3	12.3	19.2
Total soluble solids (Brix)	Average	16.6	15.0	16.6	14.3	16.4	13.9	15.7	14.2	14.2	14.4	13.7	14.5	16.4	16.1	14.4	10.4	12.7	13.0	14.6
	Minimum	10.0	8.0	12.5	10.0	10.0	9.0	9.0	8.0	9.0	12.0	8.0	11.0	11.0	12.0	8.0	8.0	8.0	10.0	8.0
	Maximum	20.0	20.0	20.0	20.0	20.0	18.0	19.0	18.0	17.5	18.0	18.0	19.0	20.0	20.0	19.0	16.0	20.0	20.0	20.0
	CV (%)	19.9	28.1	19.2	19.2	23.2	21.9	18.8	27.5	20.7	14.3	24.1	18.5	19.3	16.0	32.6	23.6	36.9	26.9	24.5
pH		4.0	3.8	4.2	4.0	3.5	3.0	3.5	3.0	3.0	3.8	3.8	3.0	3.0	3.6	4.0	3.5	3.0	3.0	3.5
Titratable acidity (% citric acid)		0.52	0.52	0.54	0.54	0.50	0.46	0.50	0.47	0.45	0.52	0.52	0.46	0.46	0.52	0.54	0.49	0.46	0.47	0.50

The TSS variable recorded an average of 14.6 ºBrix (CV= 24.5 %), with a variation from 8 to 20 ºBrix. On average, 38.9 % of the farms recorded values higher than 15 ºBrix (Table 1; Figure 2A). These TSS values found in feijoa in Tungurahua were similar to those reported by Rivas *et al*. (2024) in Uruguay-type feijoa (10.6 to 23.6 ºBrix) and by Sánchez-Mora *et al*. (2019) in Brazilian germplasm (5.6 to 18.3 ºBrix). In New Zealand commercial cultivars, TSS values have ranged from 10.1 for the cultivars Anatoki and Smith, up to 16.3 ºBrix with the cultivar Opal Star (Pasquariello *et al*., 2015; Zhao *et al*., 2023). In the cultivar Quimba in Colombia, values of 10.3 to 13.4 ºBrix have been reported (Parra-Corrado *et al*., 2015). In Brazilian feijoa cultivars (SCS411 Alcântara, SCS414 Mattos, SCS412 Helena, SCS415 Nonante and Accession 2316) values of 9.3 to 13.8 ºBrix have been reported (Amarante *et al*., 2017; Santos *et al*., 2022).

In relation to fruit pH, a variation of 3 to 4 was obtained, with an average of 3.5 and CV= 12.6 %. The fruit recorded an average acidity of 0.5 % citric acid, with a variation of 0.45 to 0.54 %, and CV= 6.4 %. Farms F9, F6, F13, F13, F17, F8 and F18 had the lowest pH values (3), and citric acid values of less than 0.47 %; while F1, F4, F15 and F3 recorded pH values between 4 and 4.2, and acidity values of 0.52 to 0.54 % citric acid (Table 1; Figure 2A). These values were similar to those found in Brazilian commercial cultivars whose pH ranged from 2.45 to 3.68 for SCS412 Helena and SCS411 Alcântara, respectively (Amarante *et al*., 2017); and fruit acidity, ranged from 0.53 to 0.65 % citric acid, for SCS414 Mattos and SCS411 Alcântara, respectively (Santos *et al*., 2022). In Uruguayan germplasm, titratable acidity values between 0.24 and 1.97 g citric acid.100 mL^{-1} pulp juice have been recorded, with an average of 0.85 g (Puppo *et al*., 2014); while, in Colombia, in the Quimba variety, titratable acidity ranged between 1.7 and 1.9 % citric acid in the locality of Tenjo and between 1.6 and 1.9 % citric acid in the locality of San Francisco (Parra-Corrado *et al*., 2015).

The principal component analysis (PCA) of the 18 feijoa farms showed that the first two components PC1 and PC2 explained 59 % of the variation in the data (Figure 2B). The first component explained 38.4 % of the variability, through the variables: diameter (0.569), length (0.567) and fruit biomass (0.497); while the second component explained 20.6 % of the variability, where pulp yield (0.793) and pericarp thickness (-0.538) contributed mostly to explain this variation. Similar results were found by Citadin *et al*. (2022), who when characterizing 99 feijoa trees found that the first two components explained 65.2 % of the variation, with the variables fruit biomass, pulp yield, TSS and fruit diameter/length ratio being the most highly correlated with the components.

These results were in agreement with Borsuk *et al*. (2017), who, when evaluating feijoa fruits from 18 natural populations in southern Brazil, found that PCA explained 89.8 % of the variation, and the variables that contributed most to the variability in the components

were diameter, length, fruit biomass, pericarp biomass, pulp biomass, pulp yield and TSS. In the evaluation of 178 feijoa genotypes, Sánchez-Mora *et al*. (2019), found that the first two components of PCA explained 56.0 % of the variation in the data, and the variables biomass (-0.54) and, fruit diameter (-0.48), pericarp thickness (-0.45), pH (-0.66) and titratable acidity (0.64) contributed the most to the variability.

The variables fruit diameter and fruit length showed significant correlation (r= 0.91***) and were highly correlated with fruit biomass (r= 0.85***; r= 0.90***), suggesting that they are reliable parameters of feijoa fruit size (Figure 2B). The characteristic pericarp thickness was correlated with yield (r= -0.50*), being evident that fruits with higher pericarp thickness affected pulp yield (Figure 2B). In Brazil-type feijoa, Sánchez-Mora *et al*. (2019), found highly significant correlations between fruit biomass with diameter (r= 0.85) and fruit length (r= 0.66), and between pulp yield and pericarp thickness (r= -0.59). According to Donazzolo *et al*. (2017), fruit diameter and fruit length could serve as indirect selection criteria to increase the biomass of feijoa pulp. The variables titratable acidity and pH were reported to be highly correlated (r= 0.96***), showing that the fruits were ready to initiate the dynamic ripening process. Significant correlations between titratable acidity and pH (r= -0.49) were observed in Brazilian feijoa germplasm (Sánchez-Mora *et al*., 2019).

In Figure 2B, it is possible to observe that fruit from farms F7 and F2 showed a wide dispersion, indicating high intra-farm variability, while fruit from farms F11 and F13 were more concentrated, suggesting greater homogeneity. Farms F1, F2, F7, F11 and F15 were strongly clustered with larger fruit size, as evidenced by fruit diameter, length and biomass. Meanwhile, farms F14, F5, F4, F10 and F13 reported larger diameters in pericarp thickness and TSS. Higher pulp yields were observed in fruits from F8 and F3. Fruits from F16 were smaller in size. Fruit size and quality characteristics of feijoa could be related to crop management, such as irrigation, fertilization, pruning, thinning, pest and disease control, among others.

Conclusions

Feijoa trees in the province of Tungurahua, Ecuador, show similar characteristics to the Uruguay type. Fruit length and diameter were highly correlated with fruit biomass, suggesting them as determinant variables in the selection of trees with commercial potential. The PCA identified farms F1, F2, F7, F11 and F15 as having better physico-chemical characteristics of the fruit as evidenced by fruit diameter, length and biomass, presumably due to crop management and genotypic characteristics of the trees. The observed variability in the evaluated traits indicates considerable potential for increasing productivity through the implementation of appropriate agronomic management practices, as well as for initiating a breeding programme.

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