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RESEARCH PAPER

Morphological characterization of sweet chestnut fruits from forest plantations in central Chile

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Abstract

S. Benedetti, F. Balocchi, M. Gonzalez, and P. Garcia-Chevesich. Morphological characterization of sweet chestnut fruits from forest plantations in central Chile. 2018. Cien. Inv. Agr. 45(2): 138-146. The sweet chestnut (*Castanea sativa* Mill.) is one of the most important starchy foods worldwide due to its low fat content and high nutritional value. This study is the first analysis of the sweet chestnut fruit in forest plantations where the morphological properties are characterized, in terms of caliber, size, shape, and internal cracking, damage, and cavities. The study was based in three sites in Chile, Los Rios Region (39°S), where most of the forest chestnut plantations are located. Scott and Knott test of variance and contingency tables were used as statistical methods for site comparisons. In general, no significant differences in size were found among sites. Moreover, the Chilean forest sweet chestnut can be defined as a small-caliber fruit with slight internal cracking and internal damage and almost no cavities. Therefore, due to its morphological characteristic (especially caliber), it has the potential to be used for secondary food products.

Keywords: *Castanea sativa,* fruit size and shape, Los Rios region, Scott and Knott.

Introduction

The European chestnut (or sweet chestnut, *Castanea sativa* Mill.) was introduced in Chile in the early 1800s (Grau, 2003). Its current distribution within the Chilean territory ranges from 34°S to 41°S latitudes (Grau and France, 1998; Joublan *et al.,* 2004). Originally from the northern hemisphere (mostly Europe and Asia) (Pereira-Lorenzo and Ramos-Cabrera, 2004), its fruit, the "sweet chestnut", is one of the most important nuts worldwide (Kan *et al.,* 2017) due to its combination of high carbohydrate contents and low protein and fat contents (Saavedra, 1981; Dinis *et al.,* 2008).

This species is mainly found in central Chile as fruit orchards covering a total estimated area of 339 hectares (Instituto Nacional de Estadística

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[INE], 2007), distributed over the Andes foothills. In contrast, only a few forest plantations can be found, ranging from 1 to 30 hectares, in the south of Chile between Los Rios and Los Lagos Region (39°- 41°S latitudes). The relevance of this study is that the forest plantation scope is wood production, where the trees are planted at a high density (3×3 meters) with no fruit varieties. While the production cycle is between 30 to 35 years, it was important to analyze the quality and potential of its fruit as a commercial option for plantation owners until wood harvest. Additionally, this species is especially important in Chile because it does not have relevant diseases attacking trees and fruits (Joublan *et al.*, 2004).

Many studies in Europe have focused on the morphology of this fruit from natural forest conditions. Mujić *et al.* (2010), for example, described sweet chestnuts in Bosnia and Herzegovina, finding the smallest chestnuts within the Mediterranean area of Europe. On the other hand, Ertan (2007) studied morphological, pathological, and biochemical specs of the sweet chestnut in Turkey, where a large interaction between genotype/year was found. Similarly, Poljak *et al.* (2012) characterized the Croatian sweet chestnut fruit's morphology, finding significant differences between trees and populations in the fruit's morphology, especially fruit weight. Serdar and Soylu (1998) selected Turkckeysh chestnut types with best nut qualities such as size, color, and thickness, whereas Solar *et al.* (1998) in Slovenia characterized seven preselected chestnut fruit types, identifying the three best genotypes in this area (marron type) according to their number of fruits per bur, size, number of fruits per kilo, shape, cavities, episperm penetration, stripes, and sweetness. Finally, in a Croatian study, Poljak *et al.* (2016) characterized the quality and productivity of seven Lovran Marron morphological chestnut fruits, defining them as "attractive".

Despite the above, little is known about the morphology of sweet chestnut fruits from forest plantations in Chile, and just a handful of studies have focused on this interesting fruit. Grau (2003), for example, studied 12 European fruit cultivars from Italy, France, and Japan using morphological fruit parameters and found a marron-type fruit. However, this study was done in fruit from chestnut orchards and not from forest plantations, as in the present study. Additionally, Benedetti *et al.* (2012) focused on germination and physical characteristics of chestnut from two forest plantations in Los Rios region, finding no significant differences between them. Considering the above statements and the lack of knowledge in this particular area, the objective of this study was to characterize the morphology of fruits from Chilean sweet chestnuts from forest plantations.

Material and methods

Study site

The study site was located in Los Rios region, where the most relevant concentration of forest chestnut plantations is found. Three sites (Figure 1) with similar characteristics were selected: Las Minas, 39°55´16.89´´ South latitude, 73°13´54.9´´ South longitude; Pillo Pillo, 39°52´27.41´´ South latitude, 73° 06´59.48´´ South longitude; and Pumillahue, 39°39´10.52´´ South latitude, 72°46´30´´ South longitude. All are properties of "Forestal Tornagaleones", a Chilean private forestry company. The plantation density was 3x3 meters, and trees were planted in 1978, 1980, and 1982, respectively.

Two sites were located along Chile's coastal range, Las Minas and Pillo-Pillo, and the third, Pumillahue, was in the central valley, with altitudes of 58.44, and 155 meters above sea level respectively. In general, the three sites have similar climate characteristics, with a mean annual temperature between 10.5 °C and 16 °C, maximum annual temperature ranges from 21.4 °C to 22.7 °C, and minimum temperature between 3.1 °C and 4.7 °C. Finally, mean annual rainfall is between 1600 mm and 2300 mm (Centro de Información de Recursos Naturales [CIREN], n.d.).

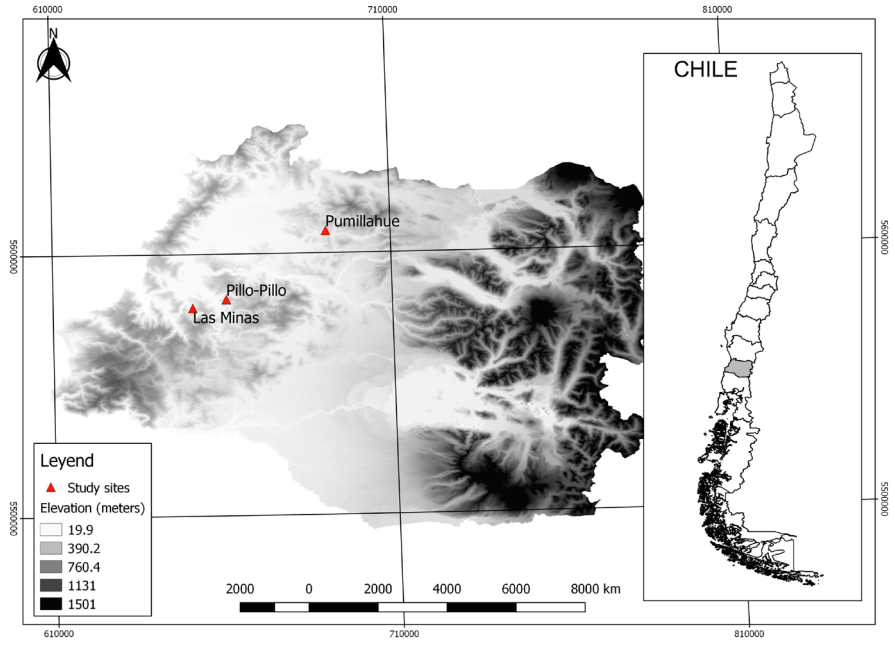

Figure 1. Location of the three study sites within Los Rios region and its location within Chile (gray).

In terms of soil properties, the three sites have similar conditions, characterized for being "good" soil conditions for the species: deep, light, well-drained soils, with loamy textures, and the presence of organic and litter layers (Benedetti and Saavedra, 2007). All climate and edaphic values were located within the Medel's parameter determination (Medel, 1986) for chestnut production in Chile.

Sampling procedure

To evaluate the fruit caliber a random statistic design was applied with ten chestnut fruits samples from each site, during harvest season in April 2008. Each fruit sample was one kilogram, weighed in the field and then in the laboratory, for validation purposes. To analyze the other morphological parameters considered in this study (i.e., internal cracking and internal damage, a random subsample of 30 fruits was selected, from each of the ten one-kilogram samples per site).

Morphological parameters analysis

Two morphological parameters (size and shape) were used for chestnut characterization. Each parameter was described according to several variables (Bolvanský and Mendel, 2001; Grau, 2003; Martín *et al.*, 2008; Dinis *et al.,* 2008). The variable "size" was evaluated based on caliber (number of fruits/kg), length (mm), width (mm),

Table 1. Definition of each additional quality parameters.

Parameter	0	1	2	3
Cracking	Without presence of testa	Slight presence of testa	Medium presence of testa	Full fruit partition
Internal damage	No damage	Slight damage	Medium damage	Severe damage
Cavity	No cavity	Slight cavity	50% cavity	Severe cavity

and thickness (mm). In relation to "shape", two indices were used: "R1" (ratio between fruit width and fruit length) and "R2" (ratio between fruit thickness and fruit length). Additionally, the quality of the fruit (in terms of percentage) was evaluated based on the fruit's internal cracking, internal damage, and the presence of cavities as shown in Table 1. Internal damage, expressed in percent (or number of damaged fruits over 100 fruits per site), referred to the presence of fungi or any other internal alterations. A contingency table was built in order to compare categorized data. A binary value was assigned in terms of the presence or not of fruit damage (i.e., "1" in presence of damage and "0" otherwise).

Later and to avoid the overlapping process of some test of variance (e.g., Tukey, 1949), the Scott and Knott cluster analysis (Scott and Knott, 1974) was performed to evaluate significant differences (p-value < 0.05) between parameters on each analyzed site (SK test hereafter). To do this analysis, the ScottKnott R package was used.

Results and discussion

Caliber and size parameters

The number of fruits per kilogram (f kg^{-1}), or caliber, was significantly different among all sites (Table 2). Pumillahue had the highest mean fruit/kilogram (135.6 f kg^{-1}), sharing the same standard deviation as Las Minas, the latter having the lowest mean fruit/kilogram (106 f kg^{-1}). In contrast, Pillo-Pillo's mean fruit/kilogram was between those from the two other sites (110.8 f kg^{-1}), but with a lower standard deviation. These results were validated with the analysis of variance was performed, which found significant differences among all sites for this parameter. The above results could be derived from the different climate conditions in the Pumillahue sites, being the only sites with one dry month, less annual precipitation, and more below-freezing days.

Based on results from Ayfer *et al.* (1977), caliber values of the Chilean sweet chestnut fruits from forest plantations can be classified as "small", similar to the Asturian chestnuts (Díaz-Hernández *et al.,* 2003). Regarding Las Minas sites, its caliber value is similar to the Gallega's chestnuts, with 106 f kg^{-1} (Pereira-Lorenzo and Fernández-López, 1997a, b), and those by Pereira *et al.* (2005) in Asturias, Spain, where 80% of their sites had 100 f kg^{-1}.

This small caliber condition obtained in this study, is confirmed when we compared it to Grau (2003) studies about the marron-type fruits introduced in Chile from Italy, France, and Japan, obtaining calibers between 67 and 99 f kg^{-1} from high-quality trees, and similar to the results of Noria´s (2000) study on chestnut orchards in the Andes foothills of Biobio region whose measured mean caliber values were between 52 and 59 f kg^{-1}.

In general, the size parameters present a similar behavior in all sites (Table 2). In fact, it is possible to fit the data into a normal distribution. However, the intervariability in Las Minas for these parameters, within three sites, seems higher. This variability can be related to geographic location differences, especially with the coastal or marine influences (sites near the Pacific Ocean), which usually alleviate summer drought (Gondard *et al.,* 2001) and the possibly higher soil moisture content in this region. It is important to point out that length, width, and thickness are some of the most important fruit characteristics defining the commercial value of sweet chestnut (Soylu and Ayfer, 1993).

Mean length value was nearly 27 mm, while the variance analysis suggests a slight difference in Pillo-Pillo sites, with the highest value among all sites (2 mm). However, Las Minas sites had a higher standard deviation, which in general is higher than the values obtained in other studies (e.g., Mujić *et al.,* 2010), and this might be related to the small sample size.

Table 2. Descriptive statistics for all sites: caliber, size, and shape parameters (different letters in the same column mean statistically significant differences in SK test, p-value<0.05).

Sites		Caliber (f kg^{-1})	Length (mm)	Width (mm)	Thickness (mm)	R1	R2
Las Minas	Mean	106.00 b	27.13 b	29.43 a	16.68 b	109.10 a	61.64 a
	Std. Deviation	12.8	3.3	3.7	3.3	12.3	11.1
	Minimum	82.0	17.7	17.9	6.8	72.6	33.3
	Maximum	127.0	35.1	38.7	29.2	135.8	109.2
Pillo-Pillo	Mean	110.8 b	28.6 a	29.4 a	17.5 a	103.0 b	61.4 a
	Std. Deviation	8.0	2.6	3.3	2.4	10.2	8.4
	Minimum	99.0	21.7	20.9	10.7	77.2	42.1
	Maximum	125.0	36.7	41.05	28.23	128.42	98.98
Pumillahue	Mean	135.6 a	26.8 b	28.9 a	16.1 c	108.4 a	60.1 a
	Std. Deviation	16.4	2.6	3.7	2.8	12.4	9.4
	Minimum	108.0	17.1	17.5	6.0	75.7	35.0
	Maximum	153.0	33.1	44.5	25.7	151.3	94.4

In terms of width, the homogeneity of these values matches with the variance analysis from the SK test (Table 2). In fact, the width parameter was the only one with no significant differences among sites. Even though this parameter got the highest variability compared to all others, it should be noted that these chestnuts are more rounded (similar height and width). The mean thickness values were approximately 17 mm. All sites had similar mean values (16.68, 17.48, and 16.07 mm for Las Minas, Pillo Pillo, Pumillahue, respectively), with higher data dispersion in Las Minas, suggesting that the thickness parameter is more vulnerable to little changes in its value, because the magnitude of the value itself was significantly lower. This, in part, could explain why SK test showed significant differences among all sites (Table 2).

In regards to mean values for size parameters (length, width, and thickness (Table 2)), the results coincide with those by Dinis *et al.* (2008) from Murca in Trás-os-Montes and Alto Douro, Portugal, with 27.4, 25.65, and 14.51 mm for length, width, and thickness, respectively. Additionally, these results agree with those by Martín *et al.* (2008), for the early variety in Andalucía.

Shape parameters

In relation to the shape parameters, the R1 parameter (Table 2) appears to be similar among sites (103, 108, and 109 for Pillo-Pillo, Pumillahue, and Las Minas, respectively). However, the K variance test showed that only Las Minas and Pumillahue had similar values, which could mean that the two sites are from the same provenance. Additionally, standard deviation values showed high variability; a behavior that can be explained because R1 is calculated using length and width, this relationship assimilates both variances inside the parameter. These results match those by Dinis *et al.* (2008) for chestnuts from different areas in Trás-os-Montes and Alto Douro in Portugal. Pillo-Pillo sites had values similar to those obtained by Dinis *et al.* (2008) in Carrazedo de Montenegro (R1 of 103 and 102) and Murça location (R1 of 108).

In terms of the R2 parameter, the results showed no significant differences among sites, where mean values were 61, 60, and 62 for Pillo-Pillo, Pumillahue, and Las Minas, respectively. Within each site, Las Minas had greater data dispersion,

which could be explained by having fruits wider than normal, but shorter in length. However, it should be mentioned that the R2 parameter was out of range (lower limit), because of a smaller width and larger length.

Internal cracking, internal damage, and cavity

In general, most of the fruit samples had no cracking (example on Figure 2) for all analyzed sites. According to Vieitez *et al.* (1996), the cracking is a fundamental parameter for fruit quality in Italy and France. Specifically, no cracking (0 level, Table 3) is the only level that had a significant difference among sites. In fact, Las Minas had the highest percentage at this 0 level, but no significant differences were found on the other levels (1 to 3). These results could be related to the small sample size. A low frequency of cracking level 2 and 3 could be observed from the above Table 3, having values between 7% and 12% for level 2 and 3% and 5% for level 3. These values are in concordance with the French standard for high chestnut quality, with a maximum value of 12% (Grau, 2003; Vieitez *et al.,* 1996).

Table 3. Mean subsample results for cracking and internal damage (different letters in the same row mean statistically significant differences in SK test, p-value <0.05).

Sites		Las Minas	Pillo Pillo	Pumillahue
Cracking (%)	0	54 b	70 a	66.3 a
	1	29 a	19.7 a	23.3 a
	2	12 a	7.3 a	7.3 a
	3	5.0 a	3.0 a	3.0 a
Internal Damage (%)	No damage	96.3 a	97.8 a	97.0 a
	Slight damage	1.3 a	1.5 a	1.1 a
	Medium damage	2.3 a	0.4 a	1.1 a
	Severe damage	0.0 a	0.4 a	0.7 a

Figure 2. Example of no cracking, no internal damage, and no cavity. Subsample from the Las Minas site.

For the fruit's internal damage, no significant differences among sites were found (Table 3), for the mean value per site, and all sites showed a high percent of nondamaged fruits (Table 4, 97.03% mean value).

The "cavity" parameter indicated almost no cavities on all sites. In fact, just a few fruits per sample had signs of cavities or external damage. For the 900 analyzed fruits, no external damage was found (just two fruits had internal cavities). For this reason, a detailed analysis was not needed.

Table 4. Contingency table for internal damage per sites.

Sites	No damage	Damage
Las Minas	286 (95.3%)	14 (4.7%)
Pillo Pillo	293 (97.7%)	7 (2.3%)
Pumillahue	292 (97.3%)	8 (2.7%)
Total	871 (96.8%)	29 (3.2%)

The main conclusions are as follows. Even though the fruit caliber found was "small" (over 100 fruits per kilo), the sweet chestnut collected from three southern forest sites in Chile showed high quality fruits. The study results demonstrated a healthy fruit without partitions, internal damages, and cavities. Such fruit quality is similar to a marron-type chestnut. In general, comparing these results with European chestnut-related studies, Chilean fruits from forest plantations have similar values in shape (length, width, and thickness) and size (R1 and R2 parameters). Among sites, no significant differences were found, but some parameters such as width had high homogeneity, whereas the thickness parameter had high heterogeneity. Therefore, and due to its morphological values (especially caliber), the Chilean sweet chestnut fruits from forest plantations have the potential to be used for secondary products such as jam, mash chestnut, and flour. Moreover, a starch analysis is needed to be able to infer whether the Chilean sweet chestnut is a high-quality starchy fruit, as is the case for other chestnuts around the world.

Resumen

S. Benedetti, F. Balocchi, M. Gonzalez, y P. Garcia-Chevesich. Caracterización morfológica de frutos de castaña provenientes de plantaciones forestales en Chile Central. 2018. Cien. Inv. Agr. 45(2): 138-146. El castaño (*Castanea sativa* Mill.) es uno de los frutos almidonados más importantes a nivel global dado su bajo contenido de grasas y alto valor nutricional. En el presente estudio, se caracterizó morfológicamente al fruto del castaño en términos de su calibre, su tamaño (i.e. largo, ancho y grosor), su forma (R1 como la relación entre el ancho sobre el largo y R2 como la relación entre el ancho y el grosor), y también su partición interna, el daño interno y su cavidad interna. El estudio se desarrolló sobre tres rodales ubicados en la Región de Los Rios, Chile (39°S), lugar que concentra la mayor superficie de castaño en Chile. Los rodales se compararon estadísticamente usando la prueba de prueba de Scott y Knott, además de tablas de contingencia. En general, no se encontraron diferencias significativas entre rodales. Asimismo, el fruto del castaño estudiado puede ser definido como de calibre pequeño, con una baja partición y daño interno, además de casi nula cavidad. Por lo tanto y dado los resultados (especialmente el de calibre), el fruto analizado proveniente de rodales con fines madereros, tiene un alto potencial como productos secundario, como por ejemplo para mermelada, puré de castañas y harina.

Palabras claves: *Castanea sativa*, Región de Los Rios, Scott y Knott, tamaño y forma del fruto.

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