

Article

Chili Pepper Landrace Survival and Family Farmers in Central Chile

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Abstract: Chili pepper is produced by family farmers in central Chile incorporating modern technologies and maintaining traditional practices. Although chili pepper is deeply rooted in the local culture, the agricultural system supporting its production and the germplasm involved are poorly studied. This work focused on two main landraces lacking information about what features (agronomic, morphological and chemical) distinguish them and how distinct they are. It is also of high importance to deepen our understanding of the agricultural system and the aspects that may affect its sustainability. An integrated approach was applied for the evaluation of social characteristics of farmers, the growing system, morphological traits, and selected chemical components. Between landraces, flower and fruit morphology was clearly distinct. Total phenolic content, antioxidant capacity and total carotenoid content showed higher values in fruits of *cacho de cabra* than in *chileno negro*. Both landraces had a higher total phenolic content than other *Capsicum* cultivars in the world. Farmers ascribe distinct attributes for the landraces regarding agronomic performance, fruit quality and processing applications. Characteristics that may affect the sustainability of the agricultural system are small farm size, relatives working as employees, and low farmers' educational attainment. The study landraces are distinct and represent unique genetic material produced in an agricultural system facing important challenges where farmers have adapted to socio-economic pressures, externalizing plant production, reducing harvest costs, and developing innovations in product and marketing.

Keywords: *Capsicum*; landrace; conservation; family farmers; antioxidants

1. Introduction

The genus *Capsicum* originated in Bolivia, although the five species with economic importance were later domesticated in different parts of the American continent [1]. The most ancient evidence of the presence and consumption of chili peppers dates back to 6100 y BP in Ecuador and 6000 y BP in Mexico [1].

In Chile, pre-Columbian inhabitants consumed chili pepper from 2300–2200 y BP according to the oldest archaeological evidence [2]. During colonial times (16th to 18th centuries), chili pepper was a fundamental element in the diet of the lowest social classes [3].

In modern times, chili pepper is produced and consumed regularly in Chile. In 2009–2017, the average area planted with chili pepper in the country was 848 ha, with two regions (Coquimbo and Maule) having 72% of that area. The main use of the crop produce is for fresh consumption. There are no specific data on chili pepper produced by family farmers, but 54% of the national crop area devoted to vegetables is cultivated by family farmers. For chili pepper crop production, family farmers have incorporated modern technologies such as the use of synthetic

fertilizers, pesticides and commercial cultivars. At the same time, they have maintained traditional practices for crop management and landraces.

A traditional chili pepper product is *merkén*, a spice prepared by the Mapuche people [4] that faces an increasing national demand in recent decades. *Merkén* evolved from being a spice mostly consumed within Mapuche communities to a commercial product of wide acceptance in the national markets and a distinctive ingredient of the Chilean gastronomy [5].

Among several traditional chili pepper cultivars in Chile, *cacho de cabra* and *chileno negro* are the main landraces in the region of Maule. While *cacho de cabra* has been ascribed to *C. annuum* L. [6], *chileno negro* can be included in *C. baccatum* L. [7]. *Cacho de cabra* is well-known in Chile [8] and has been recently considered part of the cultural heritage of the country [9], with great importance as a main ingredient for *merkén* [4]. Although *cacho de cabra* is probably the most renowned of local landraces in Chile, there is a surprisingly scarcity of published studies on this cultivar. For the rest of Chilean landraces, there are hardly comments in the literature—the majority mentioning the names of the cultivars and brief observations. This is well illustrated for the cultivar *chileno negro*; the only three references in published documents come from recent undergraduate works [10–12].

The local cultivars *cacho de cabra* and *chileno negro* fit well the working definition of landrace [13]. They correspond to cultivated populations with historical origin, they have a distinct identity and lack formal crop improvement, and they are locally adapted and produced within traditional farming systems. Landraces are very important as genetic resources and as components of the local culture and history, providing identity to the territory and being a central part of the agrobiodiversity. Today, despite the consumer's interest in quality local food products and development programs supporting traditional and innovative products, there is a risk of extinction of many landraces that are cultivated by a very limited number of farmers [14]. The local chili pepper cultivars in Chile also fit this situation.

The aim of the present work was to know what features, if any, distinguish poorly known chili pepper landraces and the agricultural system where they remain in Chile, and how distinct those landraces are. An integrated approach was applied for a broad characterization, including social characteristics of farmers, the growing system, morphological traits, and selected chemical components.

2. Materials and Methods

2.1. Geographical Setting

The two studied cultivars are traditionally cultivated in two main localities in the region of Maule in central Chile (Figure 1). Villa Prat (35°05'20" S, 71°36'30" W, 80–90 m above the sea level) is on the south bank of the river Mataquito, and Palmilla (35°48'30" S, 71°44'20" W, 100–120 m above the sea level) between the rivers Achibueno and Putagán. Topography and soils in central Chile are diverse and agriculture uses preferentially flat positions and irrigated soils. Both localities have soil slopes in the range of 1–4%, soil pH 6.2–6.3, and are Inceptisols. Soils in Villa Prat were originated in recent alluvial sediments, while in Palmilla, they are of lacustrine sedimentary origin. Soil texture is sandy loam in Villa Prat with excessive drainage and silty clay loam in Palmilla with poor drainage [15]. The climate in both localities is Mediterranean, with a warm, mesothermal temperature and an average maximum daily temperature of 29 °C in January (summer) and 13 °C in July (winter), and an average minimum daily temperature of 12 °C in January and 4 °C in July. Annual rainfall is 530 mm in Villa Prat and 690 mm in Palmilla, mostly occurring from May to August [16]. Wind speed in Villa Prat ranges from 1.75 (June) to 3.90 km/h (December) and in Palmilla from 4.00 (May) to 6.75 km/h (December). Sunshine duration is 9 h in winter (June) and 16 h in summer (December) (National Agroclimatic Network; www.agromet.inia.cl).

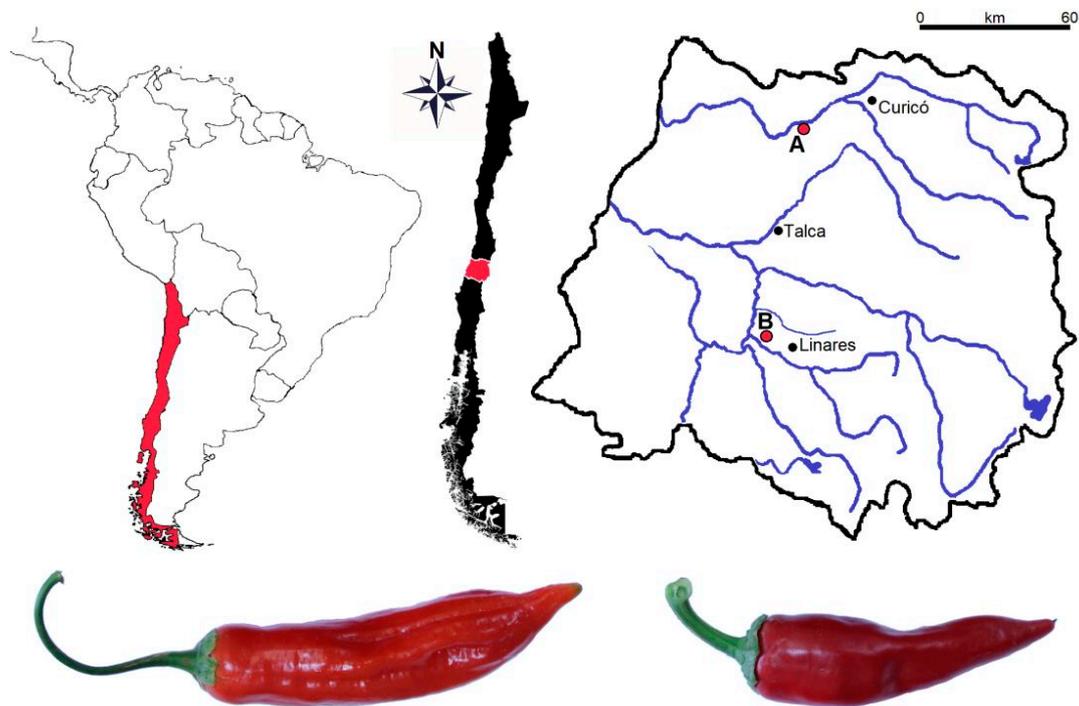


Figure 1. Chile and the region of Maule with the main cities, rivers, and the two study localities. (A) Villa Prat and (B) Palmilla. The two main landraces of chili pepper produced in these localities are *chileno negro* (left fruit) and *cacho de cabra* (right fruit).

Modern industrialized agriculture and family farmers are both present in the area. Industrialized agriculture is devoted to fruit orchards and vineyards for foreign markets, while family farmers produce vegetables and annual crops for the national market.

2.2. Agricultural System Characterization

A participatory rural appraisal (PARA) was applied in the context of a technology transference project funded by the local government (“Transferencia Mejoramiento de la AFC ligada al cultivo del Aji”). The method was developed for the collection of traditional knowledge associated with plant genetic resources using a comprehensive approach and recognizing the value of that traditional knowledge [17]. The method includes semi structured interviews and group discussions, caring for the participation of all members of the community who can bring their knowledge about the crop and its uses, including men, women and elderly people.

2.3. Selection of Interviewees

According to available data from the Instituto de Desarrollo Agropecuario (INDAP—Ministry of Agriculture, Chile) and agricultural extension services of local counties, in the 2012–2013 season (agriculture cycle in Chile spans from springtime in August to fall in April), there were a total of 41 producers cultivating chili pepper in both localities. The size of a representative sample ($n = 36$) was calculated using the formula for finite population sampling; however, 38 interviews were applied.

The authors state that all experimental protocols were conducted in accordance with the Declaration of Helsinki and approved by the institutional licensing committee (Comité de Ética Científica of the Universidad Católica del Maule, reference number 64/2018), confirm that informed consent was obtained from all interviewees, and confirm that all methods were performed in accordance with relevant guidelines and regulations.

2.4. Interview Design

The variables included covered farm size, land use, land property and water rights, family or paid external workers. Regarding the crop production system, the information collected included seed acquisition, cultivars characteristics, crop management, harvest, production volume, yield, product purpose and processing, and markets. Five old farmers willing to share their knowledge were interviewed with more detail.

2.5. Flower and Fruit Evaluation

In the two main localities where the traditional landraces of chili pepper are produced, growers were contacted, and 7 field crops were visited. In the fields 1, 3, 4 and 7 the landrace *cacho de cabra* was cultivated, while in the fields 2, 5 and 6 *chileno negro* was produced.

The evaluation procedure and selected traits followed the indications from IPGRI (1995) [18]. Flower and fruit traits were selected when they proved to be discriminant in previous studies (Rivera et al. 2016), and included fruit weight, fruit length, fruit diameter, pericarp thickness, fruit volume, petiole length, petiole diameter, number of seeds per fruit, and seed weight. Fruit weight per seed and fruit-to-petiole length ratio were calculated.

Twenty flowers and 30 mature fruits from each field were randomly collected and transported in a cool box to the laboratory. Fruits from an additional field (number 10, not visited) were collected after 5 days of sun drying, and were evaluated for variables not affected by dehydration (fruit weight and seed weight excluded). Plants were labeled in the field in order to collect all the fruits at the end of the season for measuring total fresh and dry matter production. Fruit color was measured using a colorimeter Konica Minolta CR-400 (D-65, Tokyo, Japan) in the central portion of 30 fruits from each field. Chroma (C^*) and hue angle were calculated using CIELab 1976 color space parameters (L^* , a^* , b^*). Pericarp thickness was evaluated on 0.4 mm slices obtained from the central portion of 6 fruits from each field. The slices were placed on a white board and an image captured using a Nikon D-5100 camera (Tokyo, Japan) at a fixed distance (45 cm) with artificial illumination (4×25 W lamp). Using the software ImageJ (version 2.0.0), 10 evenly distributed measurements of pericarp thickness were made for each fruit slice. Fruit water content was determined in 20 fruits drying in an oven at 35 °C for 5 days.

2.6. Chemical Analysis

A compound sample of whole dry fruits of each cultivar was sent to a laboratory (Instituto de Nutrición y Tecnología de los Alimentos—INTA, Universidad de Chile). Routine procedures were followed for the analyses of total polyphenol content [19], oxygen radical absorbance capacity (ORAC) [19] and 1,1-diphenyl-2-picrylhydrazyl (DPPH) [20] for antioxidant capacity, and total carotenoid content [21]. To compare results to previous studies, measurements based on dry weight were transformed to values based on fresh weight using the average water content.

2.7. Data Analysis

For data obtained from interviews, descriptive statistics and normality tests were applied. To compare means when ANOVA showed statistical differences, T-test and Tukey were used. Variables from fruit measurements were subjected to normality and homogeneity of variance tests. Statistical tests were applied with the software PASW Statistics 18 (IBM-SPSS).

Using data from morphological and color parameters for each field, a cluster analysis was performed. Data normalization and hierarchical clustering were performed using the “ward.D2” method [22]. A dendrogram was generated using Euclidean distances for node closeness. After the dendrogram showed two main groups, principal component analysis (PCA) was applied [23]. Cluster analysis and graphs were generated using the software R 3.0.0.

3. Results

3.1. Characteristics of the Agricultural System

The mean farm size was 7.6 ha in both locations. In Villa Prat, the majority of the producers had land access as renters or sharecroppers, while in Palmilla, most families had their own land and rented additional surface (Table 1).

Table 1. Number of producers of chili pepper with cultivars *cacho de cabra* and *chileno negro*, grouped by land tenure and their farm area.

Land Tenure	Villa Prat		Palmilla		Total		Farm Area (ha)		
	N	%	N	%	N	%	Mean ± SD	Min	Max
Only owned land	6	31.6	1	5.3	7	18.4	11.9 ± 11.7	2.5	35
Owned and rented land	1	5.3	14	73.7	15	39.5	9.9 ± 8.8	3.0	38
Rented land or as sharecropper	12	63.2	4	21.1	16	42.1	3.5 ± 1.7	2.0	8
Total	19	100.0	19	100.0	38	100.0	7.6 ± 8.1	2.0	38

The total population of chili pepper producers was 125 people with a mean family size of 3.29 (min 1, max 9). In most families (52.6%), at least one person worked as an employee outside their own system, mainly in agricultural activities (70.6%). The majority of those in charge of the production system were men (89.5%), who had a mean age of 53.7 years (min 26, max 82) with an average of 9 years of formal studies; 60.5% had assisted only to primary education, with no gender differences for age or education. For the majority of the farms (94.7%), the producer was assisted by an average of 2.1 relatives in the production activities. When the helper was a woman (40%), she was generally the producers' wife; child work was not present.

The most important crop type by area was vegetables: chili pepper, tomato (for industrial purposes and for fresh consumption), watermelon, melon, and leafy vegetables. The second group was cereals: maize, wheat and rice, the latter only present in Palmilla. The third was potatoes, with the rest of the soil being used for cattle grazing (Figure 2). Chili pepper cultivars produced by local farmers, in addition to *cacho de cabra* and *chileno negro*, include *crystal* (*C. baccatum*, only produced by one farmer in Villa Prat), *mexicano*, and *mezcla* (mixture of *cacho de cabra* and *mexicano*). The mean area devoted to chili pepper is 1.6 ha. There were 11 individual crop production units producing *cacho de cabra* (mean ± SD area was 1.5 ± 1.1 ha), 17 with *chileno negro* (1.9 ± 1.3 ha) and 17 with other cultivars (1.4 ± 0.8 ha) (Figure 3). The total area destined to chili pepper production by all interviewees was 73.2 ha.

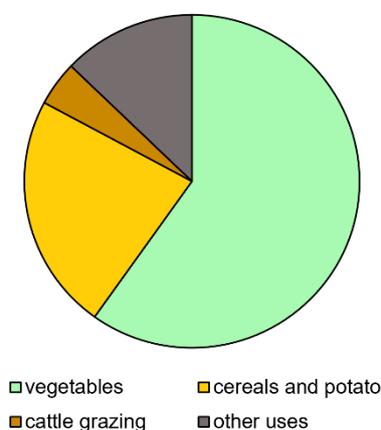


Figure 2. Land use in farms of chili pepper producers in Villa Prat and Palmilla, Maule, Chile.

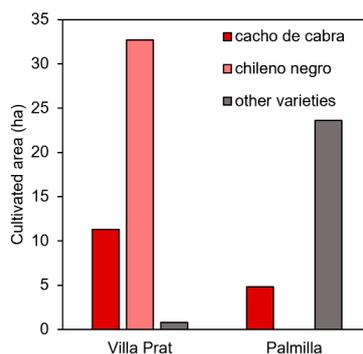


Figure 3. Cultivated area of chili pepper landraces by locality.

3.2. Crop Production

In this agricultural system, the majority of the producers (78.9%) collect their own seed, applying traditional techniques of fruit selection and seed conservation. Before harvest, fruits are collected, selecting those of smooth skin, red color, mature, healthy aspect and with the shape of the cultivar. After sun drying, seeds are extracted and kept in the producer's home for the next season. Producers allow neighbors to collect fruits. They usually interchange seeds and knowledge among members of the local community.

Seedlings are initiated in mid-winter, traditionally after the 16th of July (a religious festivity, "Virgen del Carmen"). Fertilization is given by chicken or lamb manure, and also with commercial fertilizers. The seed is not treated, but they apply fungicides to prevent damping off in seedlings. Seedlings are ready for transplant after 70–75 days after sowing.

Soil preparation is done using a tractor, but rows are traced using horses. Herbicides and insecticides are used before the plantation. Fertilizers are applied at plantation (October), a month later with an inter-row tillage (early November), and when flowering (mid January). Most families hire machine work, with only 28.9% owning tractor and equipment. Weeds are controlled with manual or horse-powered inter-row tillage, although herbicides are also used in response to the rising costs of the workforce. Furrow irrigation is provided by nearby rivers, gravitationally or using diesel water pumps once a week or every two weeks.

The majority (86.6%) of families hire people to work in the plantation, weed control, harvest or processing, generally without a formal work contract. Work is payed by hourly wage or piece rate systems. Especially among related families, there are also reciprocity and cooperative work systems.

The harvest of red mature fruits is traditionally made through repeated tasks (*cortas*) lasting 2–5 days each, starting in the height of the summer (mid-February) and finishing with the first frosts in fall (May). Following one '*corta*', the producers usually wait for 15–16 days before repeating the task. However, because of the workforce cost, the number of *cortas* per season has been reduced to one or two. Producers currently harvest when 80–85% of fruits are red, collecting all fruits, including those that are green but fully grown.

3.3. Agronomic and Processing Characteristics of Cultivars

Producers recognize distinct attributes for both cultivars regarding agronomic performance, fruit quality and processing applications (Table 2). The average yield informed for *chileno negro* was 26.5 ± 4.6 t/ha ($n = 17$, min 20.0, max 35.7), while for *cacho de cabra*, it was 15.9 ± 7.1 t/ha ($n = 11$, min 3.0, max 26.7), which are significantly different (T-Student, $p < 0.001$). The reported water content in fruits is consistent with that measured in the laboratory (Table 3). Regarding disease susceptibility, it is worth noting that *cacho de cabra* is especially prone to yield loss in fields affected by virus-like symptoms, which the producers consistently refer to as *aquintralado*.

Table 2. Attributes of two Chilean landraces of chili pepper informed by local producers.

Attribute	Landrace	
	<i>chileno negro</i>	<i>cacho de cabra</i>
<i>Plant production</i>		
Seeding rate (g)	ca. 500	ca. 600
Seedling area for 1 ha of crop (m ²)	20	22
<i>Crop production</i>		
Planting density	26,000–34,000	38,000–45,000
In-row spacing (cm) for 75 cm row spacing	40–50	30–35
Plant growth	+	–
Disease susceptibility	–	+
Yield	+	–
<i>Fruit quality</i>		
Water content	+	–
Pericarp (skin) thickness	–	+
Fruit length	–	+
Fruit diameter	+	–
Red color intensity	–	+
Pungency	–	+
<i>Commercialization</i>		
Produce sold by grower	Fresh fruits	Dehydrated/smoked fruits
Main final product	Fermented sauce	Spice

Table 3. Fruit measurements in two chili pepper landraces.

Trait	Landrace	
	<i>chileno negro</i>	<i>cacho de cabra</i>
Fresh weight (g)	24.6	14.3
Dry weight (g)	4.5	3.6
Water content (% w/w)	42.0	26.8
Total phenolic content (mg GAE/100 g)	838	325
Antioxidant capacity (ORAC, μ mol ET/g)	11,159	13,723
Antioxidant capacity (DPPH, mg EAA/100 g)	14,486	16,835
Total carotenoid content (mg carotenoids/100 g)	3.5	4.2

GAE: gallic acid equivalent; ORAC: oxygen radical absorbance capacity; ET: Trolox equivalent; DPPH: 1,1-diphenyl-2-picrylhydrazyl; EAA: ascorbic acid equivalent.

All interviewees agreed that the cultivar *chileno negro* is the preferred one used for fermentation (Figure 4). *Cacho de cabra* produce is mainly processed, dehydrated, smoked or not, and sold as whole fruits or ground product. Fruits are dehydrated in open air or in a special building. Dehydration in open air is the most ancient process and is done by the sun on cleaned ground directly on the soil or over a carpet for 15–20 days. Fruits are turned over every one or two days to prevent marking. Dehydration in a special building called a horno (oven) or zaranda allows the product to be additionally exposed to smoke. Non-smoked dried fruits are usually sold whole, while smoked fruits can be sold whole or ground.

The majority (78.9%) of producers add value to their produce, but only 13.2% comply with sanitary regulations for food processing. The most important process is fermentation for sauce production (Figure 4), where two types of producers can be distinguished: those who produce more than 8 t of sauce and sell wholesale, and those who produce less than 0.15 t and sell directly to consumers. The second process is smoking, where 8 out of 20 producers sell to traders in their farms, and 12 sell as wholesale fruit in vegetable markets in southern cities of the country. A third process is

sun drying, the only available for dehydration 50–60 years ago, as producers of both localities informed. At that time, most of the produce was sold as whole fruit and quality was severely affected by marking because of the sun or fungi. To prevent this, producers developed their current buildings heated by wood fire. At present, only a small amount of the total production (17.6 t, 8.3%), including all cultivars of chili pepper, is transformed to *merkén* and sold directly to consumers.

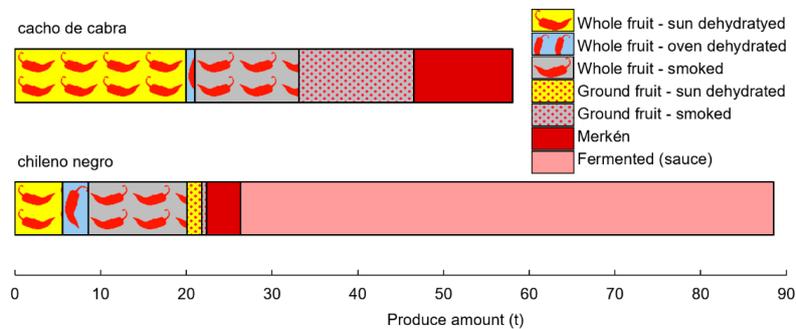


Figure 4. Amount of fruit processed (dry weight in t) by type of produce, by local farmers of two Chilean landraces.

3.4. Flower and Fruit Evaluation

Stark differences were observed between flowers of both cultivars (Figure 5). Corolla color was white in both cultivars, with a light yellow hue in *chileno negro*. A yellow mark was present in the corolla of the latter. Anther color was brown in *chileno negro* and blue in *cacho de cabra*. Small and curved appendages were observed in the calyx of *chileno negro*.

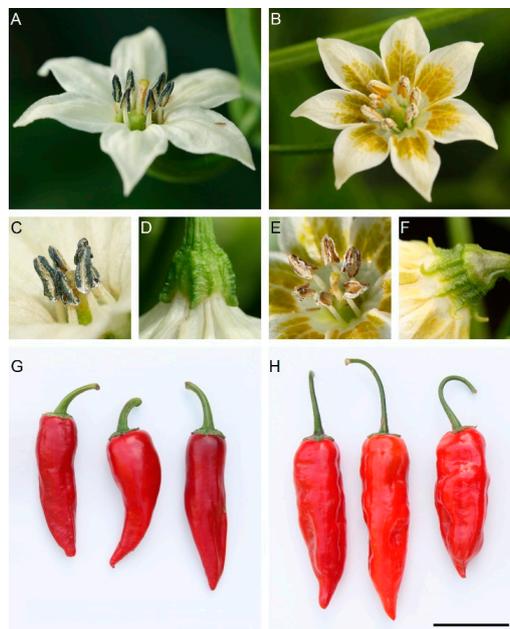


Figure 5. Flowers and fruits of Chilean landraces of chili pepper. (A) Flower of *cacho de cabra* with details of anthers (C) and calyx (D). (B) Flower of *chileno negro* with details of anthers (E) and calyx (F). (G) Fruits of *cacho de cabra*. (H) Fruits of *chileno negro* (scale bar = 5 cm).

Morphological fruit traits changed significantly among fields (Table 4). Comparing the two landraces, the only morphological variables showing consistently significant differences were petiole length, petiole diameter, and fruit-to-petiole length ratio (calculated) (Table 4, Figure 6).

Table 4. Average values for each measured variable in chili pepper fruits of different fields and landraces.

Variable	Landrace						Statistical Comparisons			
	<i>cacho de cabra</i>			<i>chileno negro</i>			between Landraces		among Fields	
	Average	SE	<i>n</i>	Average	SE	<i>n</i>	Test	<i>p</i> Value	Test	<i>p</i> Value
Fruit weight (g)	25.2	1.57	4	30.8	0.71	3	T	0.057	ANOVA	<0.001
Fruit length (cm)	11.5	0.80	5	11.8	0.31	3	T	0.841	ANOVA	<0.001
Fruit diameter (mm)	28.6	0.87	5	26.8	1.12	3	T	0.313	ANOVA	<0.001
Fruit volume (mL)	41.4	4.21	5	49.8	0.71	3	T	0.228	Kruskal–Wallis	<0.001
Pericarp thickness (mm)	2.2	0.07	4	2.3	0.06	3	T	0.584	Kruskal–Wallis	0.001
Petiole length (mm)	35.7	2.67	5	71.4	4.57	3	T	0.001	Kruskal–Wallis	<0.001
Petiole diameter (mm)	4.7	0.32	5	2.9	0.03	3	Mann–Whitney	0.025	Kruskal–Wallis	<0.001
Number of seeds per fruit	272.4	26.60	5	187.7	9.49	3	T	0.082	ANOVA	<0.001
Seed weight (g)	3.8	0.35	4	3.7	0.15	3	T	0.815	Kruskal–Wallis	<0.001
Fruit weight per seed (mg)	113.1	18.83	4	178.2	8.73	3	T	0.063	Kruskal–Wallis	<0.001
Fruit-to-petiole length ratio	3.4	0.11	5	1.7	0.16	3	T	<0.001	Kruskal–Wallis	<0.001
Color parameter L*	33.2	0.50	4	34.6	0.35	3	T	0.117	ANOVA	<0.001
Color parameter a*	32.1	0.64	4	30.5	0.18	3	T	0.134	ANOVA	<0.001
Color parameter b*	14.2	0.62	4	17.7	0.25	3	T	0.012	ANOVA	<0.001
Color parameter chroma	35.1	0.83	4	35.3	0.09	3	T	0.868	ANOVA	0.003
Color parameter hue	23.7	0.51	4	30.0	0.43	3	T	0.001	ANOVA	<0.001

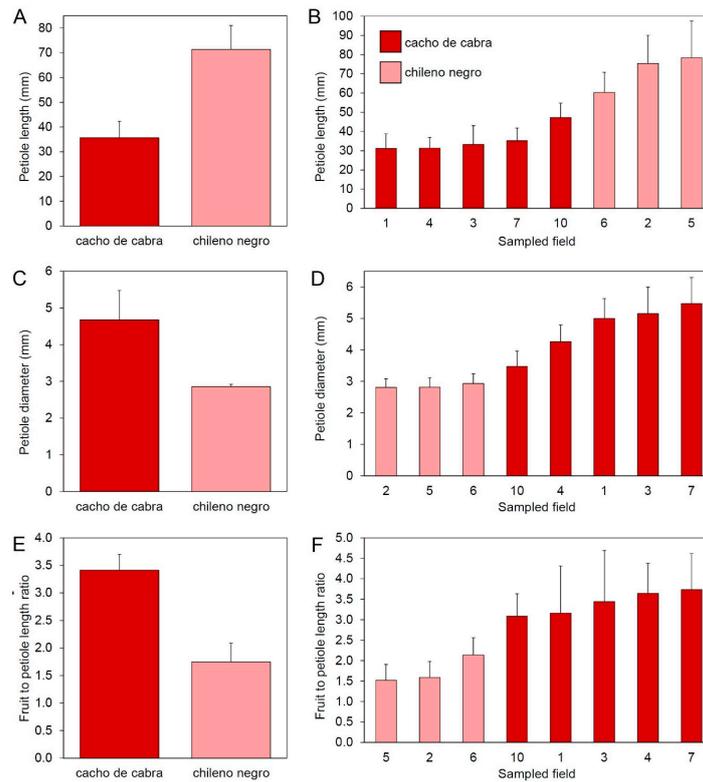


Figure 6. Morphological fruit variables differentiating Chilean landraces of chili pepper. Average values for each landrace (A,C,E) and values for individual fields sampled (B,D,F). Bars indicate standard deviation.

Fruit color in both landraces was red, with significant differences among fields for all color parameters (L^* , a^* , b^* , chroma and hue). Parameters b^* and hue showed significantly lower values for *cacho de cabra* than for *chileno negro* (Table 4). Parameters a^* and b^* had a smaller variation among fields for *chileno negro* (the difference was 0.75 for a^* and 0.97 for b^*) than for *cacho de cabra* (3.57 for a^* and 3.44 for b^*) (Figure 7).

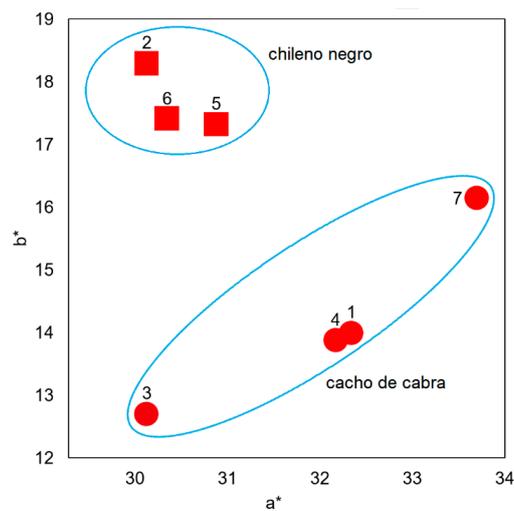


Figure 7. Relation of color parameters for chili pepper fruits from different fields belonging to two landraces. Color parameter a^* represents bluish-green/red-purple hue component, and b^* represents yellow/blue hue component. Symbol colors were generated using average field measurements.

The dendrogram for morphological and color data from fields showed two distinct groups, corresponding to the study landraces (Figure 8A). The partition plot created with two groups also showed separated clusters corresponding to the landraces (Figure 8B).

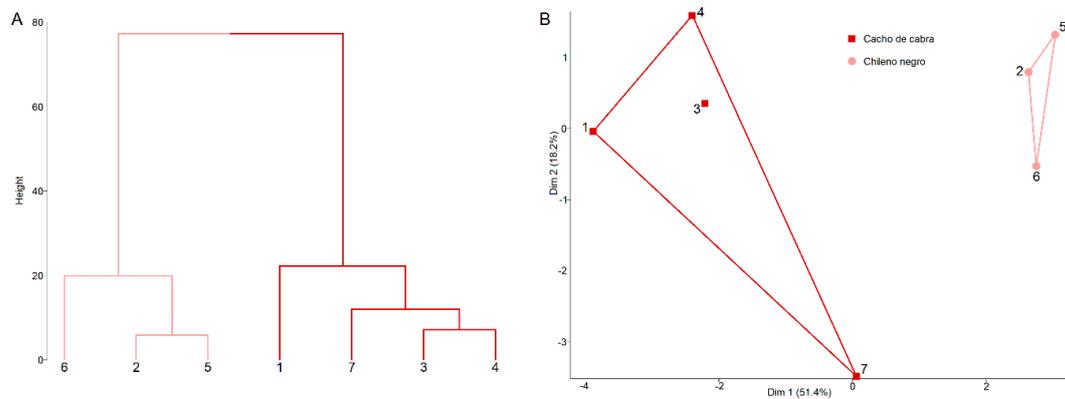


Figure 8. Cluster analysis for field data using morphological and color parameters. (A) Dendrogram and (B) partition plot generated by principal component analysis. Fields with the same landrace are grouped distinctly.

3.5. Chemical Analysis

Evaluation of total phenolic content, antioxidant capacity and total carotenoid content showed higher values in *cacho de cabra* than in *chileno negro* for all the analyses (Table 3).

4. Discussion

4.1. History and Tradition of Chili Pepper

The producers consider that this crop is an old tradition within their communities. They recognize that this activity has been inherited from previous generations lost in ancient times. Indeed, this plant was consumed and cultivated in central Chile under the rule of the Inca Empire in pre-Columbian times [24]. From colonial documents, it is clear that the crop was part of the Mapuche culture [25] and that agriculture was a flourishing activity in the lands of nowadays Villa Prat and the Mataquito valley [26]. In the early 19th century, at the end of the colonial period, traditional agricultural products for home consumption in central Chile included chili pepper [3], with a renowned production center in the Mataquito valley at the beginning of the 20th century [27].

4.2. Characteristics of the Agricultural System

Most of producers, especially in Villa Prat, do not own land (Table 1). They face increasing land hiring costs and they attribute this trend to land acquisition by industrial companies aiming for extensive crops. This observation confirms that the expansion of industrial agriculture influences smallholder family farmers and the traditional vegetable production system in the area, which could affect the sustainability of this productive system [28]. This constitutes a first threatening factor for the cultivation and conservation of local chili pepper landraces in the country.

In rural areas of Chile, young people with more years of formal education usually migrate out of their communities. Young people who remain in the study area are deterred from starting agricultural production as a business on their own by the high land price, and, thus, they work in the family farm or take hired land associated with their parents [29]. The migration of young people out of rural areas is a second threatening factor for the sustainability of the agricultural systems conserving chili pepper landraces.

4.3. Crop Production

Local chili pepper farmers follow their customs to produce seeds. They collaborate with neighbors, friends and relatives, allowing them to collect fruits as a seed source, also sharing seeds. They have traditional technologies such as sun dehydration on cleaned ground, used in local agriculture from pre-Columbian times [24]. In Palmilla, producers developed a technology for drying and smoking chili pepper fruits in an adobe building (*zaranda*) in the mid-20th century. The farmers keep traditional knowledge about the characteristics, qualities and uses of each cultivar. This is illustrated with the preferred use of *chileno negro* for fermented sauce, while *cacho de cabra* is suitable for dry and smoked preparation of *merkén*.

Before harvest, producers look for smooth ripe fruits of red color and with the typical shape of the cultivar. They collect fruits from several healthy plants. Fruits are sun dried, and the seeds are extracted and kept in used tin cans or plastic containers. This storage method is also used by chili pepper producers in other parts of the world [30]. The producers mention that when new seed is needed, they buy or interchange seeds from other families. The need of new seed would respond to lower yields or growth, which may be influenced by diseases carried by seeds. It is well known that there are a number of seed-borne pathogens in pepper [31]. A second cause for the need of new seed could be inbreeding depression, although *Capsicum* spp. generally do not show this problem [31], being able to cross-pollinate in very low and high proportions.

Most farmers (78.9%) produce their own seedlings, but some have externalized the process to other farmers. This may introduce a risk for the conservation of genetic variability because the selection and storage of the material is handled by a smaller number of people.

Work is payed either by hourly wage or piece rate systems. Especially among related families, there are also reciprocity and cooperative work systems. They can establish informal production and commercial societies, usually led by a relative with recognized administrative skills. Old relatives that are landowners may hire land to their descendants allowing them to use machinery, equipment, working animals and farm buildings. These characteristics show that the production units operate as family business [32].

4.4. The Landraces

The farmers indicate that *chileno negro* has been produced in Villa Prat for at least three generations, recognizing it as original to this locality. It is worthy to note the scarcity of publications mentioning this landrace, given its high importance. The variety is mentioned as cultivated in Villa Prat [11], and supposedly part of a variable type of chili pepper [33]. In a national well-known work on vegetables [8], *chileno negro* is even not mentioned.

In Palmilla, the farmers have the landraces *mexicano* and *mezcla*; *mexicano* would have been introduced more than a decade ago by a producer who shared the seeds with their neighbors. As a result, the majority of farmers in Palmilla adopted this cultivar. *Mezcla*, a mix of *mexicano* and *cacho de cabra*, would have been produced by a cross of these two cultivars (probably spontaneously). However, producers clearly distinguish *mezcla* from their progenitors. Consistently, an elderly farmer near Villa Prat reported that 10–15 years ago, a Mexican cultivar was introduced, although it was not further cultivated in the Mataquito valley.

The farmers recount that in the past, they also produced other chili pepper cultivars such as *limenso*, *asta de cabra*, *americano* and *putamadre*. The most common cultivar was *cacho de cabra*. Gradually, the farmers reduced the number of cultivated cultivars, choosing the ones with higher yields and lower susceptibility to diseases. Losses in the diversity of vegetable landraces have also been observed in other parts of the world [34].

The replacement of traditional landraces by foreign or commercial cultivars and the trend towards the reduction in the number of used landraces pose risks for the conservation of unique genetic material and the sustainability of the agricultural system. The conservation of vegetable landraces is also highly important for genetic breeding and local communities' nutrition [35,36].

4.5. Agronomic and Processing Characteristics of Cultivars

Water content in fruits reported by farmers (Table 2) is consistent with that measured in the laboratory (Table 3). Because of the difference in yield, water content, and disease susceptibility, and since the producers are paid by fresh fruit weight, the cultivar *chileno negro* is the preferred for fermentation (Figure 4). Assuming that most of the dry produce is sold in markets out of the region of Maule for the preparation of *merkén*, the cultivar *cacho de cabra* is the most important for this product (39.1%). This agrees with the market preference and trend to mention this cultivar for the commercialization of chili pepper products. Although *chileno negro* represents 17.7% of the total dry produce, there are no references to this cultivar in the market. Moreover, *chileno negro* provides 98.2% of the raw material for the preparation of fermented sauce.

In contrast to other vegetables produced in the area, 78.9% of farmers add value to chili pepper. However, only 13.2% comply with sanitary regulations for food processing. This prevents further addition of value by processing and packaging, creating an opportunity that local farmers can explore.

4.6. Flower and Fruit Evaluation

Most morphological fruit variables showed high variability among sampled fields. This suggests that fruit characteristics are highly influenced by the environment, e.g., soil type, irrigation and diseases. An eloquent example is fruits from fields 1 and 4, originated from the same seed source and therefore with a very similar genetic base, but they showed significantly different values for fruit weight, fruit length and fruit diameter. The producer of those fields clearly stated that there is an effect of the “land” (soil, management and other environmental factors) influencing the fruit, although he also pointed out that different seed sources can produce subtle fruit shape differences.

Between landraces, most variables had no significant differences. Petiole length, diameter and fruit-to-petiole length ratio did show significant differences between the landraces, and consequently can be used to discriminate them. Petiole length in *cacho de cabra* was 22.3–49.0 mm and 52.0–90.8 mm in *chileno negro*, while petiole diameter in *cacho de cabra* was 3.1–6.3 mm and 2.7–3.0 mm in *chileno negro*. However, 50% of growers explicitly perceived that *chileno negro* fruit is commonly shorter and with a larger diameter than *cacho de cabra*, which we could not confirm with our measurements.

The red color in mature fruits of chili pepper depends on the accumulation of carotenoids and anthocyanins [37,38], which is favored by moderate air temperatures and marked variation, especially with cool nights [39], conditions occurring in the study area. As *chileno negro* presented a narrower variation for color parameters, its fruit color development would be less influenced by the environment compared to *cacho de cabra* (Figure 7). A high correlation for parameter a^* values to the antioxidant capacity and total phenolic content in Korean red varieties of chili pepper has been found [40], a relation that may also be present in Chilean landraces. Although fruits were collected on the same day, some color variation within field can be attributed to the continuous production of flowers and fruits by plants. Fine differences and relationships with diverse fruit traits of chili pepper have been found using CIELab measurements [40,41], although, in some cases, with limited discriminant capability [37,42]. In the present study, color quantification allowed us to discriminate both landraces (Figure 7).

Combining morphological and color data from the fields, the cluster analysis reinforced the differentiation of the two landraces (Figure 8), supporting the use of morphological evaluations to discriminate the landraces. The fact that samples from *cacho de cabra* spread over a greater area may indicate that this landrace has a greater phenotypic variability than *chileno negro*.

Producers observe that the fruit shape of *chileno negro* tends to be straight, while *cacho de cabra* is curved with a twisted appearance. Growers are able to clearly distinguish fruits of both cultivars, although distinct descriptions were not always delivered. Among the traits surveyed, the most useful to differentiate unequivocally both landraces are flower characteristics, especially marks and color of corolla, anther color, and calyx appendages. Useful fruit characteristics are petiole length and petiole diameter.

For future genetic breeding involving these landraces, further research and discussion is needed to explore the fruit ideotype. This will also be of importance for the identity and cultural aspects of cultivars, which must not be dismissed in breeding programs.

It will be of interest to review the taxonomy of Chilean landraces, while genetic studies will also help to better understand how cultivars are related, especially the two studied here and those cultivated in Palmilla (*mexicano* and *mezcla mexicano-cacho de cabra*).

4.7. Chemical Analysis

Total phenolic content in *chileno negro* was in the upper end of the range for 51 Brazilian accessions of *Capsicum* species, while in *cacho de cabra*, it was 32% over the highest value [43]. *Cacho de cabra* represented 90% of the value measured in a Mexican type of *C. annuum* (jalapeño) [44]. Comparable values of total phenolics to those found in *cacho de cabra* were reported in a Japanese cultivar of *C. frutescens* L. [45]. The study cultivars have a high total phenolic content compared to other *Capsicum* cultivars. In particular, *cacho de cabra* has probably one of the highest values among traditional cultivars of *C. annuum*.

Antioxidant capacity (ORAC) in *cacho de cabra* was higher than in *chileno negro* and 23% of the highest value measured in Mexican cultivars of *C. annuum*. [46]. Antioxidant capacity was 15% of that measured in *C. frutescens* [45] and 19% of the highest value reported for red dry fruits of *C. annuum* [44]. Values were similar to those reported for pepper, although *cacho de cabra* was 7% over the level reported for an unspecified Chilean cultivar [47].

Antioxidant capacity measured as DPPH and total carotenoid content were higher for *cacho de cabra* than for *chileno negro*. This is consistent with the values observed for total phenolic content and ORAC. Considering the highest value of the main carotenoid (capsanthin) present in red cultivars of pepper [48], which in turn can represent 35–70% of total carotenoid content, we can estimate the total carotenoid content to be up to 2.4 mg/100 g in fruits of *Capsicum* species. This indicates that both Chilean cultivars have a high level of these compounds. Carotenoids are pigments with an important role in nutrition and human health as precursors of vitamins and with antioxidant and anticarcinogenic activities [48].

Peppers are an important source of natural antioxidants in the diet, playing a protective role against lipid oxidation in food. Therefore, the cultivars *chileno negro* and *cacho de cabra* may represent a relevant source of antioxidants, and a valuable germplasm material for high phenolic content. Fruit maturity and processes such as drying can significantly affect the antioxidant properties of the product [44,47]. Accordingly, differences in antioxidant properties of products should be expected depending on harvest conditions, sun or firewood drying, and smoking or fermentation.

4.8. Landrace Conservation and Family Farmer Strategies

Rural communities within the centers of crop diversity have played a key role in the domestication, selection, genetic breeding and conservation of species and cultivars by centuries or millennia through collective and familiar work [49]. This has been internationally recognized by the Convention on Biological Diversity, and the International Treaty on Plant Genetic Resources for Food and Agriculture [49,50].

Landraces are generally produced in agricultural systems that are lower in input intensity and higher in agrobiodiversity than industrial agricultural systems. Plant diversity maintained by indigenous communities, peasants and family farmers are under threat because of the preference of high-yield commercial cultivars and the use of high-input technologies [51]. Facing these changes and pressures from their biophysical and socio-economic environment, farmers adapt and innovate by developing knowledge and strategies to survive as independent farmers and, at the same time, preserving their traditional crops [51]. More specifically, farmers have re-organized production factors, developed strategies to persist in the market, specialized production, organized among farmers to add value, and commercialized collectively. These strategies have been interpreted as resistance

and continuity processes for farmers, who face pressures from globalization, climatic change, and market de-regulation.

In the study area, farmers have adapted by taking decisions such as plant production externalization, reduction of harvest costs, and product innovation through the development of new chili pepper-processed products. They have also developed product differentiation using new packaging systems, labeling and brands, exploiting traditional and territorial attributes linked to chili pepper production. Additionally, farmers have been working closely with public institutions (i.e., the Ministry of Agriculture and local counties) to engage in local markets where they directly sell their products. These collective and familiar actions can be considered as resistance and continuity strategies based on chili pepper production.

Chili pepper landraces have been conserved in these adaptive agricultural systems. However, pressures from higher production costs, importation of low price chili pepper, expansion of industrial fruit production, high land prices, ageing farmers, and migration of young people are threatening the sustainability of these agricultural systems and the conservation of landraces of chili pepper and other plant species.

Further discussion to advance in the conservation of local agrobiodiversity involves three aspects. First, public policies with impact in the conservation of agricultural biodiversity in Chile have focused on ex situ seed conservation and funding initiatives recording or innovating on activities working with local crops with gastronomic or touristic interest [52]. We think that schemes involving in situ conservation can also be included in the country's public policies. Second, the functions of local seed curators have been promoted by some non-governmental organizations and farmer associations [53]. However, there is still ample space to reinforce the functions of local seed curators for the conservation of agrobiodiversity in Chile. Finally, it is important to intensify the value that society assigns to agrobiodiversity, which can be addressed by education and promotion. These three areas should be regarded as complementary. A society aware of the importance of local biodiversity will responsibly consume products from family farmers and consequently the economy of these agricultural systems will be sustained. Additionally, the society will support public policies to conserve landraces and local crops.

We believe that the conservation of the study landraces is currently under threat because few farmers are producing them. Moreover, market changes, such as the use of imported dry chili pepper, may replace local production. However, if the trend towards valuing and consuming local and heritage products continues, the use of those landraces can be promoted in the future.

It is worth to note the fragmentary formal (scientific) knowledge of the agricultural biodiversity in Chile. This is eloquently illustrated by the meagre published information on landraces such as in chili pepper. Consequently, efforts are needed to study and sustainably utilize biodiversity as a highly relevant component of agricultural systems.

5. Conclusions

The landraces *chileno negro* and *cacho de cabra* are different according to their morphological and chemical characteristics. Petiole length in *chileno negro* had an average of 71.4 mm and a petiole diameter of 2.9 mm, while in *cacho de cabra*, petiole length had an average of 35.7 mm and a petiole diameter of 4.7 mm. The two cultivars are utilized for distinct processing and final products. *Chileno negro* is preferred for fermentation to produce sauce, while *cacho de cabra* is dried and sold as raw material for the preparation of *merkén*. At present, only a small amount of the production (8.3% of all cultivars) is transformed into *merkén* and sold directly to consumers.

Despite the importance of the landraces, there is a notable lack of information in the scientific literature. These cultivars have a high total phenolic content and total carotenoid content compared to other *Capsicum* cultivars in the world. In particular, *cacho de cabra* has probably one of the highest values of phenolic content (1325 mg GAE/100 g) among traditional cultivars of *C. annum*.

Both cultivars may represent a relevant source of antioxidants in the diet and a valuable germplasm material for high phenolic content.

The traditional system for chili pepper production shows the current validity of collective knowledge held by agricultural and ethnic communities for the conservation of genetic resources. The characteristics of this productive system are still maintained despite the adoption of technologies from an industrialized agricultural model. Local producers recognize that the cultivars *chileno negro* and *cacho de cabra* are original from Villa Prat and Palmilla in the region of Maule.

In addition to maintaining familiar and collective strategies, farmers have adapted to pressures, reducing costs, externalizing activities, developing product and marketing innovations, and collaborating with public institutions. Threats to the sustainability of the agricultural system and the conservation of chili pepper landraces include increasing costs in land access, migration of people out of rural areas, and replacement of traditional landraces.

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