


# Anthropogenic pollen, foraging, and crops during Sierras of Córdoba Late Prehispanic Period (Argentina)

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## Abstract

The palynological study carried out in seven archaeological sites from Sierras of Córdoba Late Prehispanic Period (ca. 1500–360 yr BP) is presented in this article. The fossil pollen was used to assess the late prehispanic subsistence and mobility patterns based on their impact on local vegetation. Analogues obtained from modern vegetation and human-induced cultivation settings were used as a guideline for interpreting the ancient pollinic spectra. Results showed that anthropogenic pollen dominated by chenopod-amaranth plants occurred during a period of increased moisture and significant cultural change, where on-site farming and increasing occupation redundancy were identified. Thus, human disturbance and cultivation are thought to be the probable cause for elevated Chenopodiaceae–Amaranthaceae percentage in fossil assemblages. Consequently, the late prehispanic societies were likely modifying vegetation more extensively than had been previously assumed and the composition of 'pristine' landscape was not only altered by climate change or after the Europeans' arrival. The ancient clearing of the forest for farming, housing, and/or other activities played a dynamic role in land cover conformation. So, the archaeological study of mixed foraging and cultivation economies needs to encompass human–plant–landscape interaction, leaving behind the concept of small-scale societies as passive foragers exploiting the ecosystem.

## Keywords

analogy, anthropogenic landscape, Chenopodiaceae–Amaranthaceae, cultivation, hunting–gathering, late Holocene, palynological archaeology

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## Introduction

Most archaeological interpretations of the Sierras of Córdoba Late Prehispanic Period (Argentina; ca. 1500–300 BP) assumed that food production through plant cultivation quickly derived in a new mode of socioeconomic organization with a high reliance on domesticated plants – mainly maize (*Zea mays*) – and a sedentary way of life in year-round pit-house villages (Aparicio, 1939; Berberían, 1984; Berberían and Roldán, 2001; Canals Frau, 1953; González, 1943; Laguens and Bonnín, 2009; Serrano, 1945). Fortunately, the development of regional research during the last decade challenges this assumption, discrediting this unilinear point of view.

The multiple-available evidence suggests that late prehispanic people were more residential mobile than the classic view, shifting settlement location and group size according to changing circumstances (Medina et al., 2016). During the growing season (September–April), few extended families settled in semi-permanent villages or hamlets to planting maize (*Z. mays*), beans (*Phaseolus* spp.), and squash (*Cucurbita* sp.) in small plots. When harvest and storage activities finished, co-residential groups dispersed across the landscape to forage and maintain the sociopolitical fluidity upon which they depended. The decline of foraging opportunities at early growing season was followed again by seasonally co-residence and small-scale farming. Therefore, the late prehispanic people made a flexible land-use strategy based on mobile foraging and occasional cultivation, where social unit for food production, consumption, and landscape occupation was the nuclear family (Medina et al., 2016).

Although archaeological landscape shows that prehispanic land use was extensive, there has been little evidence from sediment records to indicate the magnitude or extent of prehistoric activities. To address these issues, palynological data recovered from five Sierras of Córdoba open-air archaeological sites are evaluated here: C.Pun.39 (Valle of Punilla), Boyo Paso 2, Arroyo Las Chacras 3 (Valle of Salsacate), Los Algarrobos 1, and Puesto La Esquina 1 (Pampa of Olaen) (Figure 1). The land cover reconstruction is complemented with the pollen analysis from two rock-shelters: Arroyo Talainín 2 (Valle of Salsacate) and Las Chacras 2 (Valle of Punilla). The results were interpreted in terms of their cultural significance, in the framework of the late prehispanic economic and landscape use strategies. Specifically, the pollinic spectra were used to assess the late prehispanic subsistence and mobility patterns based on their impact on local vegetation, as well

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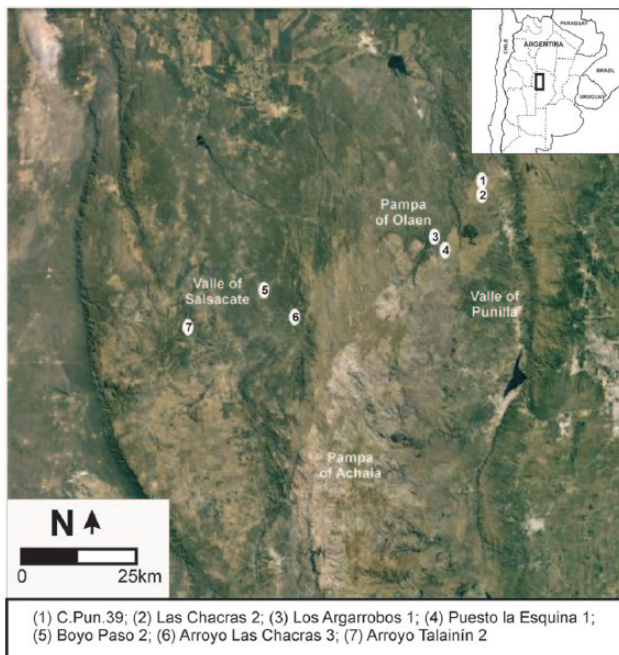
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**Figure 1.** Geographic locations of the archaeological sites referred to in text.

as to analyze the presence of crops with problem of archaeological preservation.

It is argued that the late prehispanic societies were likely modifying vegetation more extensively than has been previously assumed and that the ancient clearing of the forest for farming, housing, and/or other activities played a dynamic role in the land cover conformation. Thus, the archaeological study of mixed foraging and cultivation economies needs to encompass human–plant–landscape interaction, leaving behind the concept that the mountain ecosystem was only altered by climate change or after the Europeans’ arrival as some ecologist have believed (Díaz et al., 1993; Silva et al., 2011).

## Biogeography and paleoenvironment

The study is focused on the Sierras of Córdoba, a low-altitude mountain range (500–2800 m a.s.l.) with a complex of peaks, valleys, and high plains located in central Argentina (Figure 1). The annual rainfall is conducted mostly on late spring and summer season (October–April) and goes from 900 mm in the height environments to 600–800 mm in the valleys surrounding mountain ranges (Bridarolli and Di Tada, 1996). The isotherm of 16°C involves the mountain range, but from 2000 m a.s.l. the temperature falls to 10°C.

In a simplified scheme, most of the land cover was included in the Chaco Serrano District (Luti et al., 1979), mainly characterized by a xerophytic forest with shrubs and trees up to 15 m high (Giorgis et al., 2011). The most abundant vegetational families are Poaceae, Asteraceae, and Fabaceae, as well as Solanaceae, Cactaceae, and Bromeliaceae, that are altitudinally distributed in three vegetational belts (Bridarolli and Di Tada, 1996; Cabido et al., 1998, 2010; Giorgis et al., 2011; Luti et al., 1979).

The Sierra Chaco covered the valleys and foothills with elevation ranging from 500 to 1100–1350 m a.s.l. The tree layer is dominated by *Lithraea molleoides*, *Zanthoxylum coco*, *Schinus molle*, and *Schinopsis lorentzii*, in alternance with *Kageneckia lanceolata*, *Prosopis* spp., *Celtis ehrenbergiana*, *Geoffroea decorticans*, *Ruprechtia apetala*, and so on. The shrub layer is mainly composed of *Acacia caven*, whereas the herbs are represented by

*Dyckia floribunda*, *Deuterocohnia longipetala*, *Flourensia campensis*, *Condalia microphylla*, *Eupatorium viscidum*, and *Colletia spinosissima*. *Bouteloua* spp., *Aristida* spp., and *Setaria articulata* are the most common grass species. Of the three vegetational belts, the Sierra Chaco is the most exposed to anthropogenic threat such as fire, harvest trees for firewood, and livestock grazing because it lies close to Córdoba, the second largest city of Argentina (Luti et al., 1979).

The mountain shrubland extends along 1100 and 1700 m a.s.l., being transitional between the Sierra Chaco and the upper mountain grassland range. Shrubs are dominant (*Hetherothalamus alienus*, *E. buniifolium*, *Baccharis* sp., etc. and some cacti), covering the steep slopes.

Above 1100 m a.s.l., the upper mountain grassland range is found (Luti et al., 1979), where *Alchemira pinnata*, *Deyeuxia hieronymii*, *Stipa* spp., *Festuca* spp. *Bromus* sp., *Poa* sp., and so on are the predominant grass species. The trees are represented by *Polylepis australis* and *Maytenus boaria*, which only grow in well-protected places from the wind and livestock (Renison et al., 2004).

Paleoclimatic information indicates that the mountain vegetation during the Pleistocene–Holocene transition was different from the present. The grassland had a greater extension due to cold and dry climate conditions, connecting the high plain to lowland grasslands and precordilleran and cordilleran zones of central and northwestern Argentina (Andreazzini et al., 2013; Carignano, 1999; Krapovickas and Tauber, 2016; Piovano et al., 2009; Rivero and Medina, 2016; Sanabria and Argüello, 2003). This allowed the flow of several Andean–Patagonian flora species, including *P. australis* and *M. boaria*. The establishment of subtropical conditions at 6000 BP redefined the landscape with the formation of the Sierra Chaco vegetational belt and the biogeographical isolation of Andean–Patagonian biota above 1500 m (Krapovickas and Tauber, 2016; Sanabria and Argüello, 2003). Current oceanographic and atmospheric pattern at ca. 3000 BP emphasized the similarities between the modern and fossil biotas (Andreazzini et al., 2013; Giorgis et al., 2015; Heusser, 1990; Krapovickas and Tauber, 2016; Markgraf, 1991; Silva et al., 2011; Yanes et al., 2014), even when two climatic fluctuation were identified in central Argentina during the last 1000 years: the ‘Medieval Warm Period’ (ca. AD 900–1300) and the ‘Little Ice Age’ (AD 1300–1850). The former had subhumid/temperate climate, milder winters, higher rainfall, and hydrological surplus (Carignano, 1999; Piovano et al., 2009). The second event was contemporary to the Spanish colonial system. It was characterized by extreme droughts alternating with torrential summer rains that caused the reduction of lakes and the reactivation of erosion (Cioccale, 1999; Piovano et al., 2009).

## Archaeological sites and chronology

Boyo Paso 2 (BP2, 1160 m a.s.l., Departamento Pocho) is an open-air site located at eastern Valle of Salsacate (Figure 1). The Sierra Chaco surrounds the site, with *L. molleoides*, *G. decorticans*, *C. ehrenbergiana*, *Z. coco*, *Prosopis* spp., *S. marginata*, and palm tree (*Trithrinax campestris*), as well as a shrub layer with *F. campestris* and *A. caven*. The horizontal excavation revealed an archaeological floor with post-molds and a roughly semi-subterranean structure that was dated at 750 ± 70, 1060 ± 50, and 1500 ± 80 yr BP (Medina, 2015; Medina et al., 2016). The layout of the radiocarbon dates, artifacts, and features allows the hypothesis of the presence of residential structures such as pit-houses but that overlaps and does not look as a durable habitational residence for long-term occupation.

Arroyo Las Chacras 3 (ALCh3, 1180 m a.s.l., Departamento Pocho) is near Boyo Paso 2 (Figure 1). The area is covered by

**Table 1.** Radiocarbon dates and soil samples selected for palynological analysis.

Site	Sampled sediments	Chronology		
		Stratigraphic unit	Dated material	<sup>14</sup> C yr BP
Puesto La Esquina 1	E2 layer 3 (20–30 cm)	H1 layer 2 (10–20 cm)	Charcoal	365 ± 38 BP (AA64816)
		H1 layer 4 (30–40 cm)		362 ± 43 BP (AA64815)
Los Algarrobos 1 C.Pun.39	A1 layer 4 (30–40 cm)	A2 layer 3 (20–30 cm)	Charcoal	949 ± 40 BP (AA64818)
	D1 layer 6 (50–60 cm)	D1 layer 6 (50–60 cm)	<i>Phaseolus</i> sp.	525 ± 36 BP (AA64819)
	D1 layer 8 (70–80 cm)	C2 layer 9 (80–90 cm)	Charcoal	716 ± 39 BP (AA62339)
Las Chacras 2	D1 layers 13–14 (60–70 cm)	D1 layers 13–14 (60–70 cm)	<i>Lama</i> sp. bone	3819 ± 55 BP (AA64822)
Arroyo Las Chacras 3	B3 layer 5 (20–25 cm)	B1 layer 5 (20–25 cm)	Charcoal	917 ± 37 BP (AA100670)
Boyo Paso 2	B1 layer 6 (30–36 cm)	C1-C2-D1-D2-E1-E2 layer 3 (25–30 cm)	Charcoal	1500 ± 80 BP (LP-3107)
		C1-C2-D1-D2-E1-E2 layer 4 (30–37 cm)	Charcoal	1060 ± 50 BP (LP-
		A1-A3-B1-B3 layer 6 (30–37 cm)	Charcoal	750 ± 70 BP (LP-2932)
			Charcoal	900 ± 50 BP (LP-2269)
Arroyo Talainín 2	4b (70–80 cm)	4b (70–75 cm)	Charcoal	900 ± 50 BP (LP-2269)
		4b (80–85 cm)	Charcoal	980 ± 60 BP (LP-2262)

trees *A. caven*, *A. atramentaria*, *Jodina rhombifolia*, *S. praecox*, *P. torquata*, and *T. campestris*, along with shrubs *E. viscidum* and *Stillingia bodenbelli*. A dense concentration of pottery fragments in plan was recovered in a layer of about 10 cm thick. Habitational structures or well-preserved features were not detected yet. However, reassemblage relations led to interpret the assemblage as an abandonment refuse inside or near a house floor that was accumulated by a single component occurrence dated at 917 ± 37 yr BP, probably as seasonal-type occupation (Medina, 2015; Medina et al., 2016).

Arroyo Talainín 2 (AT2, 1030 m a.s.l., Departamento Pocho) is located in the western Valle of Salsacate (Figure 1). Its surroundings present the typical environmental characteristics of the Sierra Chaco flora, with *Prosopis* spp., *Acacia* spp., *T. campestris*, and *H. alienus*. The site covers 5000 m<sup>2</sup> and includes 81 grinding tools – mortars – with basins pecked into different unmovable rock and a small rockshelter. Only Late Prehispanic Period occupations were identified during its excavation. Charcoal obtained from a hearth area found inside the rockshelter was radiocarbon dated at 740 ± 60 yr BP (Pastor, 2007). Two overlapped archaeological floors corresponding to the initial occupation of the site were radiocarbon dated at 980 ± 60 and 900 ± 50 yr BP (Medina et al., 2011). The archaeological record suggests an intense and redundant site use from ca. 1000 yr BP to the Spanish arrival in the sixteenth century for animal and vegetal large-group food processing and consumption tasks (Medina et al., 2011).

C.Pun.39 (1050 m a.s.l., Departamento Punilla) is in northern Valle of Punilla (Figure 1). The Sierra Chaco land cover is open due to the altitude and the modern on-site farming activities, with isolated trees of *L. molleoides*, *Z. coco*, *Mimosoideae* spp., *H. alienus*, and *Stipa* sp. grassland. Introduced *Eucalyptus* sp. and *Pinus* sp. also surround the site, testifying the heavily human alteration of modern landscape. No settlement pattern data were recorded during its excavation with the exception of an ambiguous packed floor. However, the richness of the assemblages indicates that multiple domestic activities were carried out, including food production. Three charcoal samples from overlapping layers were dated at 525 ± 36, 716 ± 39, and 854 ± 39 yr BP, showing different occupation events across the Late Prehispanic Period (Medina, 2015).

Las Chacras 2 (LCh2, 1060 m a.s.l., Departamento Punilla) is a rockshelter at 1000 m south from C.Pun.39, in a lateral gorge with a xerophytic forest impacted by livestock but well protected from the land clearing for farming (Figure 1). The archaeological sequence is dominated by pottery and lithic artifacts that resemble other late prehispanic assemblages dated at ca. 1500–360 yr BP. However, the dates –126 ± 38, 154 ± 43, 466 ± 45, 560 ± 45, and 3819 ± 55 yr BP; the absence of a clear archaeological stratigraphy; the presence of European fauna; and the multiple-evidence

of bioturbation indicate the high post-depositional dynamic and a low resolution of the deposit (Medina et al., 2008). Thus, the sediments average the pollinic rain of the last ca. 4000 years, situation that impedes an accurate interpretation of the late prehispanic pollen spectra.

Los Algarrobos 1 (LA11, 1100 m a.s.l., Departamento Punilla) is an open-air site located in the western border of Pampa of Olaen grassland (Figure 1). Nevertheless, some Sierra Chaco trees – that is, *Prosopis* sp., *C. ehrenbergiana*, and *Mimosoideae* spp. – grow near the site. The surface and stratigraphic archaeological assemblages confirm that farming and residential activities were carried out on-site. A charcoal sample was dated at 949 ± 40 BP (Medina, 2015).

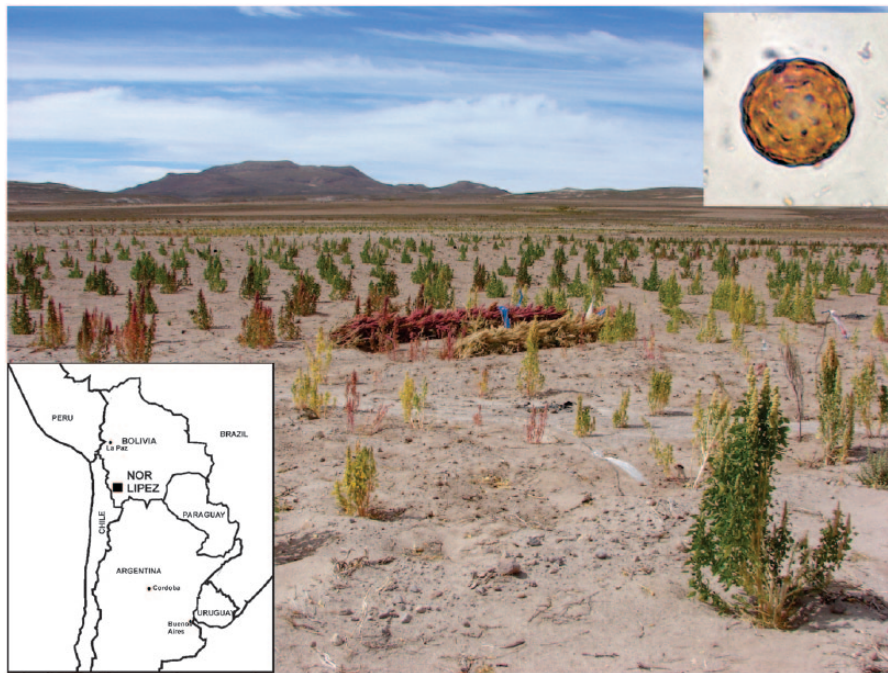
Puesto La Esquina 1 (PE1, 1140 m a.s.l., Departamento Punilla) is an open-air site located in a well-protected gorge of the Pampa of Olaen (Figure 1). The land cover is dominated by *Stipa* sp., whereas the rocky steep presents *H. alienus*. The pottery, bone, lithic, and paleobotanical evidence, as well as a presumably residential structure, indicate the development of multiple activities in connection with farming, food processing, storage, and manufacturing tools (Medina, 2015). Two charcoal samples from overlapping layers were dated at 365 ± 38 and 362 ± 43 yr BP indicating that most the elements were accumulated over the same short-span of time.

## Materials and methods

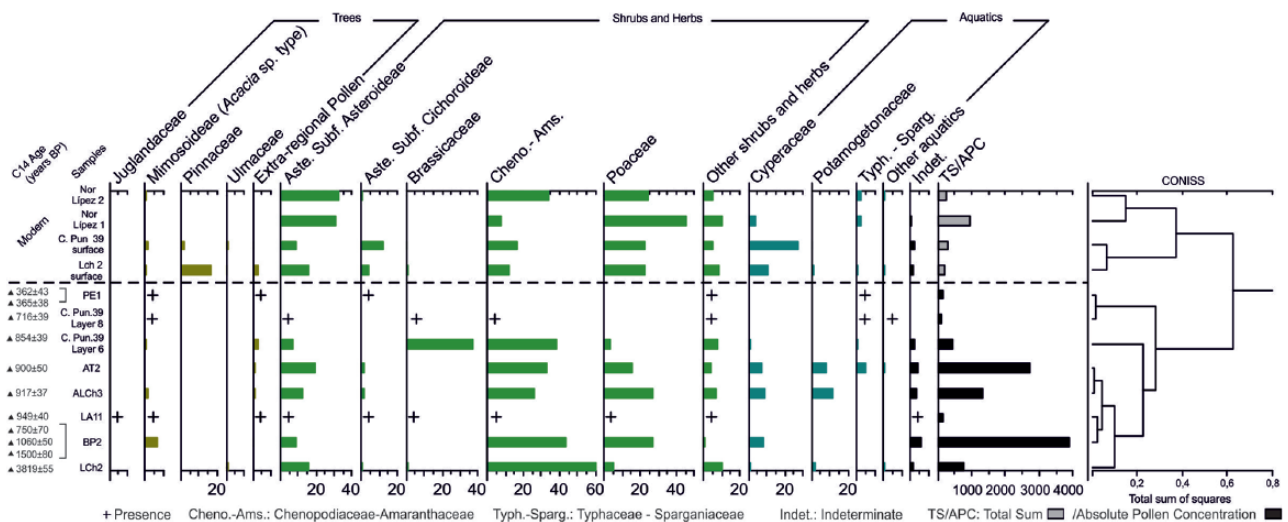
The fossil samples were collected according to the protocol described for palynological archaeology (Fish, 1994; Pearsall, 2004; Piperno, 1995). The study focused on samples well associated with radiocarbon dates for accurate interpretations (Table 1). Surface samples in C.Pun.39 and Las Chacras 2 were collected to provide a way to compare the fossil pollen assemblage with the pollen produced by modern vegetation types and control potential contamination (Piperno, 1995).<sup>1</sup> Two soil samples collected from quinoa (*Chenopodium quinoa* var. *quinoa*) farming plots of Nor Lípez (4600 m a.s.l., Potosí, Bolivia) were also used as a guideline for interpreting the Chenopodiaceae–Amaranthaceae fossil pollen grains through contemporary human-induced cultivation (Figure 2).

Fossil and modern samples were processed according to Heusser and Stock (1984). Sediments were dried, grinded in a mortar, and weighed. Twenty-five grams of each sample was selected for palynological analysis. Three tablets of *Lycopodium* sp. spores were added before the physical and chemical processing to obtain pollen concentration (grains/grams of sediments). A minimum of 200 pollen grains was considered to calculate the relative abundance of each vegetal family. Los Algarrobos 1, C.Pun.39 layer 8, and Puesto La Esquina 1 did not meet these criteria, and





**Figure 2.** Quinoa (*Chenopodium quinoa* var. *quinoa*) farming plot and *Chenopodiaceae*–*Amaranthaceae* pollen grain from Nor Lípez 2 (Potosí, Bolivia).



**Figure 3.** Pollen diagram of the modern analogues and fossil samples.

only the presence of plant families was taken into account. Pollen identification was made using an optical microscope Olympus BH2 under transmitted light. Reference collections from the Palinoteca del Laboratorio de Palinología (Universidad Nacional del Sur), published atlases, and keys were used for taxonomical identification (Hall, 2010; Heusser, 1971; Markgraf and D'Antoni, 1978; Reille, 1992). The taxonomic frequencies were plotted in a pollinic diagram performed by TGview 2.0.2 and CONNIS software (Grimm, 2004). Finally, it was assumed that if close relationship between modern analogues derived from known vegetational formation and fossil assemblage were established, then human activities can be identified in the archaeological sediments.

## Results

### Fossil samples

The pollinic spectra from Boyo Paso 2 (age:  $750 \pm 70$ – $1500 \pm 80$  yr BP) was dominated by *Chenopodiaceae*–*Amaranthaceae* (43%), *Poaceae* (26%), and *Asteraceae* subfam. *Asteroideae* (9%)

(Figures 3 and 4). Shrubs such as *Zygophyllaceae* have low percentage (<1%). The tree layer was recorded by *Mimosoideae* (*Acacia* sp.; 6.5%) and extra-regional pollen of *Podocarpaceae* (<1%). The pollen of aquatic plants was represented by *Cyperaceae* (8.2%). The absolute pollinic concentration reached 3915.4 grains/g of sediments.

In Arroyo Las Chacras 3 (age:  $917 \pm 37$  yr BP), *Poaceae* (26.6%), *Chenopodiaceae*–*Amaranthaceae* (26.2%), *Asteraceae* subfam. *Asteroideae* (12.7%), *Asteraceae* subfam. *Cichoroideae* (1.8%), and other shrubs and herbs (6.7%; *Malvaceae* and *Solanaceae*) were the well-documented families (Figures 3 and 5). The tree layer was characterized by *Mimosoideae* (*Acacia* sp.; 1.5%), followed by the shrub elements *Anacardiaceae* (*Schinus* sp.) and *Zygophyllaceae* (2%). The extra-regional pollen of *Myrtaceae* (1.1%) was recorded. Pollen of aquatic plants were represented by *Potamogetonaceae* (11.2%) and *Cyperaceae* (8.9%). The absolute pollinic concentration reached 1313.7 grains/g of sediments.

The pollinic spectrum of Arroyo Talainín 2 (averaged age:  $933 \pm 39$  yr BP) was dominated by *Chenopodiaceae*–*Amaranthaceae*



**Figure 4.** Archaeological floor and *Chenopodiaceae–Amaranthaceae* pollen grain from Boyo Paso 2 (Córdoba, Argentina).



**Figure 5.** Modern land cover surrounding the excavation of Arroyo Las Chacras 3 and *Chenopodiaceae–Amaranthaceae* pollen grain obtained from the archaeological sediments (Córdoba, Argentina).

(33.5%), Asteraceae subfam. Asteroideae (19.8%), Poaceae (15.1%), and Asteraceae subfam. Cichoroideae (1.4%). Other shrubs and herbs (4.3%) that include *Schinus* sp., Ephedraceae, Iridaceae, Labiate, and Malvaceae were also detected (Figure 3). Tree pollen has low percentage, being taxonomically assigned to extra-regional Podocarpaceae (<1%). The following pollen of aquatic plants were identified: Potamogetonaceae (8.3%), Cyperaceae (7.2%), Thyphaceae–Sparganiaceae (4.7%), and others (<1%). The absolute pollinic concentration reached 2713.1 grains/g of sediments.

Pollen concentration of C.Pun.39 layer 8 (age:  $716 \pm 39$  yr BP) was low (98 grains/g of sediments) due to the bias produced by chemical oxidation and other post-depositional process (see Medina et al., 2008). However, scarce pollen grains of Brassicaceae, Caryophyllaceae, *Chenopodiaceae–Amaranthaceae*, Convolvulaceae, Malvaceae, Oleaceae, Rosaceae-type, and Fabaceae (*Acacia* sp.) were recognized. *Myriophyllum* sp. and Thyphaceae/Sparganiaceae were identified among aquatic plants (Figure 3).

The C.Pun.39 layer 6 pollen assemblage (age:  $525 \pm 36$  yr BP) was dominated by the annuals herbs *Chenopodiaceae–Amaranthaceae* (38%) and Brassicaceae (37%), followed by Asteraceae subfam. Asteroideae (7%), Poaceae (3%), and Malvaceae (1%). The shrubs were documented by Oxalidaceae (5.21%), Caryophyllaceae, Scrophulariaceae, Solanaceae, and *Acacia* sp. were identified but in low percentage (<1%). Extra-regional pollen of Podocarpaceae (1.42%), Myrtaceae (1%), and Nothofagaceae (<1%) were also recorded (Figures 3 and 6). The aquatic plants Cyperaceae (1.42%), Thyphaceae/Sparganiaceae (1%), and indeterminate pollen grains completed the pollen association. The absolute pollinic concentration reached 445 grains/g of sediments.

Las Chacras 2 (maximum radiocarbon age:  $3819 \pm 55$  yr BP) was clearly dominated by pollen of *Chenopodiaceae–Amaranthaceae* (60%), followed by Asteraceae subfam. Asteroideae–*Bidens* sp. and *Ambrosia* sp. (16%), Poaceae (5.3%), Brassicaceae (1%), and Asteraceae subfam. Cichoroideae (1%). Other shrubs and herbs were also represented (10.4%), such as *Larrea divaricata*, Labiate,





**Figure 6.** The heavily human-altered landscape surrounding the excavation of C.Pun.39 and Brassicaceae pollen grain obtained from the archaeological sediments (Córdoba, Argentina).

and Anacardiaceae (Figure 3). The tree layer is poorly recorded by Ulmaceae (*Celtis* sp. and others; 1%). The pollen of aquatic plants were associated with Potamogetonaceae (2.1%), Cyperaceae (1%), and others (<1%), such as *Myriophyllum* sp. The absolute pollinic concentration reached 789 grains/g of sediments.

The pollen of Puesto La Esquina 1 (averaged age:  $364 \pm 28$  yr BP) has no good preservation conditions due to post-depositional process, such as the biological activity of fungi and bacteria (see Medina et al., 2008). Thus, only few pollen grains of Asteraceae, Poaceae, Chenopodiaceae–Amaranthaceae, Euphorbiaceae, Geraniaceae, Solanaceae, Zygophyllaceae, and Fabaceae (*Acacia* sp.) were identified (Figure 3). The extra-regional pollen of Araucariaceae, Myrtaceae, and Podocarpaceae, as well as indeterminate pollen grains, complete the pollinic association. The absolute pollinic concentration reached 180 grains/g of sediments.

Los Algarrosos 1 (age:  $949 \pm 40$  yr BP) was affected by similar taphonomical process to Puesto La Esquina 1 (see Medina et al., 2008). Therefore, the following pollen grains were identified in low frequency: Apiaceae, Asteraceae, Brassicaceae, Poaceae, Chenopodiaceae–Amaranthaceae, Ephedraceae, Euphorbiaceae, Myricaceae, Oleaceae, Solanaceae, Fabaceae (*Acacia* sp.), and Zygophyllaceae (Figure 3). Indeterminate pollen grains and the extra-regional trees Juglandaceae, Myrtaceae, and Podocarpaceae were also recorded. The absolute pollinic concentration reached 164 grains/g of sediments.

#### Modern analogues from Córdoba (Argentina) and Nor Lípez (Bolivia)

The surface sample of C.Pun.39 was dominated by pollen of the herb layer: Cyperaceae (27%), Poaceae (22.5%), Chenopodiaceae–Amaranthaceae (17%), Asteraceae subfam. Cichoroideae (15.3%), and Asteraceae subfam. Asteroideae (9.34%). In contrast, Brassicaceae was not well recorded (<1%). The tree pollen did not exceed 2%, even when *S. molle*, *Acacia* sp., *Celtis* sp., and *Z. coco* were identified (Figure 3).

The modern pollen assemblage of Las Chacras 2 has similar herb composition to the surface sediment of C.Pun.39 (Figure 3). Poaceae (22.5%), Chenopodiaceae–Amaranthaceae (12.5%), Asteraceae subfam. Asteroideae (11.76%), and Asteraceae subfam. Cichoroideae (4.46%) were recorded. The annual weeds Brassicaceae presented low percentages (1.5%). The exotic

Pinaceae (16.5%) dominated the tree layer, being native families less represented (<2%). The aquatic plants pollen was well documented by Cyperaceae (11.5%).

The modern analogue Nor Lípez 1 (Potosí, Bolivia) was dominated by high percentages of Poaceae (45%, *Setaria*-type, *Distichlis* sp.) and Asteraceae subfam. Asteroideae (30.8%, *Ambrosia*-type 6.3%), followed by Chenopodiaceae–Amaranthaceae (7.64%). Other shrubs and herbs were also documented: Caryophyllaceae, Convolvulaceae, Malvaceae, Papilionaceae, and *Plantago*-type (Figure 3). The pollen of aquatic plants were represented by Cyperaceae (3.93%; *Schoenus andinus*-type and *Cyperus*-type) and Thyphaceae–Sparganiaceae (2%).

The surface sample of Nor Lípez 2 was dominated by herbs such as Chenopodiaceae–Amaranthaceae (33.89%), Asteraceae subfam. Asteroideae (32.64%, *Ambrosia*-type 4.2%), Poaceae (23.85%, *Setaria*-type), and other shrubs and herbs (5.44%, Caryophyllaceae, Malvaceae, and *Plantago* sp.) (Figures 2 and 3). Aquatic pollen was also important: Thyphaceae–Sparganiaceae (2%) and Juncaginaceae-type (<1%). In contrast, the tree layer was poorly represented (<0.5%, *Acacia*-type).

## Discussion

The vegetation around the sites during the Late Prehispanic Period produced an unusual pollen assemblage, with extremely high amount of pollen of these families that represented weeds associated with disturbed ground or derived from cultivars. The pollen of Chenopodiaceae–Amaranthaceae (43–26%) and Brassicaceae (37%) dominated the fossil assemblages, having lower percentages (<17%) in modern samples. Thus, it is argued that surface samples of C.Pun.39 and Arroyo Las Chacras 2 did not represent good analogues for the late prehispanic land cover, even when the surface sediment of C.Pun.39 was collected from a farming impacted area. The alternative viewpoint outlined here is to start from the presumption that the late prehispanic vegetation represented, in the terminology of ecological theory, ‘non-analogues communities’ produced by a specific human–plant–landscape interaction based on a flexible mobility and subsistence patterns.

Floristic census conducted in the last decade suggests that Chenopodiaceae–Amaranthaceae plants are not abundant in the Sierra Chaco forest and upper mountain grassland range, even



**Figure 7.** Patch of wild Chenopodiaceae–Amaranthaceae and other weedy plants in an anthropogenically disturbed soil settings surrounding a recently abandoned farmstead (Sierras of Córdoba, Argentina).

when wild species of *Chenopodium* spp. and *Amaranthus* spp. with high edible biomass, as well as *Gomphrena* spp., *Alternanthera* spp., *Iresine diffusa*, and so on, grow in disturbed places (Cabido et al., 1998; Giorgis et al., 2011; Kraus et al., 1999; Luti et al., 1979; Nuñez and Cantero, 2000; Sayago, 1969; Sérsic et al., 2010). In contrast, Chenopodiaceae–Amaranthaceae is dominant in saline marshes surrounding Salinas Grandes and Laguna Mar Chiquita (Luti et al., 1979) ca. 100 km of the sites. Pollinic spectra with high percentages of Chenopodiaceae–Amaranthaceae are associated with saline environments (Grill and Guerstein, 1995; Mancini et al., 2005; Marcos et al., 2011; Paduano et al., 2003; Rojo et al., 2012; Schitteck et al., 2015; Vilanova et al., 2006), subhumid/arid conditions (Hanselman et al., 2005; Hansen et al., 1994; Mancini et al., 2005; Marcos et al., 2011; Oxman et al., 2013; Prieto, 2000), anthropogenic landscapes (Bray, 1995; Jenny et al., 2002; Kulemeyer et al., 2013; Paduano et al., 2003; Piperno, 1995), and/or Andean crops (Chepstow-Lusty, 2010; Hall, 2010; Hansen et al., 1994; Kulemeyer et al., 1999; Lupo et al., 2010; Schäbitz et al., 2001).

A similar situation occurs with Brassicaceae, which reaches a maximum of 37% in fossil assemblage of C.Pun.39 dated at  $525 \pm 36$  yr BP. Brassicaceae is not an important element in modern land cover, but it is associated with disturbed places (Giorgis et al., 2011; Nuñez and Cantero, 2000; Sérsic et al., 2010). *Descurainia* sp., *Mostacillastrum* sp., *Roripa* sp., and *Physaria lateralis* were identified in the Sierra Chaco, but *Exhalimolobos weddellii* and the crop weed *Lepidium bonariense* are the most abundant species (Giorgis et al., 2011; Kraus et al., 1999; Nuñez and Cantero, 2000). Palynological studies carried out in Pampean region (Argentina) confirm that Brassicaceae is well associated with anthropic or eolic disturbance (Burry and Trivi de Mandri, 2009; Grill et al., 2007; Gutierrez et al., 2011; Prieto, 2000).

Chenopodiaceae–Amaranthaceae plants are commonly characterized as ‘camp followers’ because they grow in a variety of anthropogenically disturbed soil settings that frequently surround residential sites (Bruno, 2006; Kuznar, 1993; Smith, 1992; Figure 7). The denomination could be extended to Brassicaceae, another annual plant family whose pollen is usually associated with modern and historic evidence of heavy human disturbance along with Polygonaceae, *Pinus* sp., *Eucalyptus* sp., *Carduus* sp., and so on (Borromei, 1995; Chepstow-Lusty, 2010; Grill, 1997, 2003; Trivi de Mandri et al., 2006).

The exceptional frequency of Chenopodiaceae–Amaranthaceae pollen grains in the sediments of all the sites dated on the Late Prehispanic Period suggests that plants with similar pollen type to the Andean crops quinoa (*C. quinoa*) and amaranth (*A. caudatus*) grow abundantly nearby the sites. Several arguments support that the microfossils came from small-scale farming of *C. quinoa* and *A. caudatus* and/or secondary vegetational configuration of weedy plants that included wild Chenopodiaceae–Amaranthaceae and Brassicaceae along the wild-to-domesticated continuum (López et al., 2015).<sup>2</sup>

First, the pollen of potential Chenopodiaceae–Amaranthaceae crops is presented in high percentages (26–43%) exclusively in late prehispanic deposits associated with cultivating implements and other cultigens such as maize, bean, and squash. The values increase if the high time-averaged pollen record of Las Chacras 2 (60%) is considered. These signals of crops were accompanied by pollen of Brassicaceae and Asteraceae subfam. Asteroideae (*Bidens* sp., *Ambrosia* sp., and others), weeds frequently related to extensive farming that argued in favor of an agricultural explanation (Bruno, 2014; Chepstow-Lusty, 2010; Fish, 1994; Hall, 2010; Hansen et al., 1994; McLauchlan, 2003). In addition, Chenopodiaceae–Amaranthaceae is not abundant in modern Sierras of Córdoba pollinic rain despite the high level of anthropic disturbance by fire, mechanic agriculture, harvesting tree for firewood, and cattle grazing (Figure 2). Thus, the data suggest that certain conditions are necessary for them to thrive and that more dense population than the observed today is needed to produce the amount of pollen recorded in late prehispanic spectra. In contrast, a more extensive surface sampling revealed that the closest analogue to fossil assemblage was collected from an extra-regional garden containing *C. quinoa* var. *quinoa* crops (Figure 2). Moreover, percentages ca. 40% in Andean archaeology were related to cultivation ca. 5000–3500 yr BP (Chepstow-Lusty, 2010; Hansen et al., 1994; Kulemeyer et al., 1999; Schäbitz et al., 2001).

Second, most crops do not disperse pollen over great distances. Thus, their presence in archaeological sediments provides reliable and direct data about the existence of crops near the sites (Fish, 1994: 62). This assumption is supported by the record of Chenopodiaceae–Amaranthaceae pollen clumps in Boyo Paso 2, Arroyo Las Chacras 3, Puesto La Esquina 1, and Arroyo Talainín 2, commonly used as indicator of short dispersal distance from the parent plant – that is, the plant was growing near the site of



sedimentation (Paduano et al., 2003). The low contribution of other native families and extra-regional pollen sources reinforces this argument.

Third, the geomorphological regional evidence indicates warmer and humid condition during the Late Prehispanic Period (Carignano, 1999; Piovano et al., 2009). Aquatic pollen, which might clarify the climatic interpretation, is well represented at all sites and modern analogues, discrediting that the elevated values of Chenopodiaceae–Amaranthaceae and Brassicaceae were associated with drier conditions.

Fourth, the quinoa crop was frequently mentioned by ethno-historic records from seventeenth century. For example, in a 1639 chronic, the witnesses of a land tenure trial from Valle of Punilla declared that ‘in the past the native people from Cosquin planted quinoa’ (Archivo Histórico de la Provincia de Córdoba (AHPC), Escribanía I, Legajo 72, Expediente 2, f. 75v); ‘they cultivated quinoa and squash and maize’ (f. 82v); and ‘the native people made grinding tools to process quinoa and maize’ (f. 80v).<sup>3</sup>

Archaeobotanical analysis of micro- and macroremains reinforces the hypothesis of on-site farming. For example, López and Recalde (2016) recently identified the first macrobotanical remains of domesticated quinoa (*C. quinoa* var. *quinoa*) and their weed the *ajara* or *quinoa negra* (*C. quinoa* var. *melanospermum*) in the late prehispanic site Quebrada Norte 7 (Northern Sierras of Córdoba). Both subspecies allow defending the on-site quinoa plant cultivation during the Late Prehispanic Period, discrediting the long-distance transport. *Chenopodium* sp./*Amaranthus* sp. starch grains from carbonized food residues on pottery fragment were also recovered in C.Pun.39. However, they did not show diagnostic features to identify genera at specific level (López et al., 2015). Furthermore, starch grains assigned to *Chenopodium* sp. were identified in hand-stones food residues from Component 2 (ca. 3000 yr BP) of Quebrada del Real 1 (Pampa of Achala, Córdoba), indicating the early management and consumption of *Chenopodium* sp. by human foragers (López et al., 2015).

Finally, they are high nutritional plants that are commonly identified along with maize, squash, and bean, outlining the typical ‘American tetrad’ (López et al., 2015). Moreover, the quinoa and amaranth are crops resistant to frosts and droughts, requiring a low-investment cultivating effort (Bruno, 2006). These characteristics make Andean crops optimum to stand the Sierras of Córdoba environmental adversities for farming; they seriously constrain neither the group mobility nor the time investment into other subsistence activities which provide the bulk of the overall diet as foraging.

Pollen grains of Chenopodiaceae–Amaranthaceae and Brassicaceae should also indicate that sites were recurrently abandoned and reoccupied, creating open patches where sun-loving plants may grow (Bruno, 2006; Fish, 1994; Kuznar, 1993; Pearsall, 2004; Piperno, 1995; Smith, 1992). Here, it is argued that the open-air residential sites were formed by multiple overlapping short-term domestic occupations (2–6 months), even when they were stratigraphically indistinguishable, and only a rough estimation of the occupation span can be imposed (Medina et al., 2016). The wide range of land-clearing activities carried out on sites as low-investment cultivation frequently disturbed and enriched the soil, providing an excellent long-term opportunity for the growth of early successional plants such as Chenopodiaceae–Amaranthaceae and Brassicaceae. In contrast, it is proposed that the rockshelters were formed by more intermittently and very short-term occupations (<14 days) to process wild resources and lithic raw material at familiar or communal level. However, the existence of Chenopodiaceae–Amaranthaceae peaks of 60% reflects that the human activities were intense, creating ephemeral clearing areas surrounding the rockshelter at the time of sediment deposition. These data suggest a flexible mobility pattern among the late prehispanic groups, with the abandonment of open-air sites and

farming plots to forage wild resources that were distributed in heterogeneous fashion as pointed by Arroyo Talainín 2 and Las Chacras 2. Moreover, the lack of substantial middens in the open-air sites, few evidences of year-round residences, and the low investment in farming fields support these arguments (Medina et al., 2016).

The absence of macrobotanical evidences of other Andean crops such as potatoes (*Solanum* sp.) and oca (*Oxalis tuberosa*) or lowland tubers such as sweet potatoes (*Ipomea batata*) and manioc (*Manihot* spp.), even when cited by early colonial chronics, should respond to their poor preservation conditions. Something similar occurs with the maca (*Lepidium meyenii*), another resistant crop with a high nutritional value (Chepstow-Lusty, 2010). The presence of these crops was likely included at not much taxonomic resolution in the pollen types Solanaceae, Oxalidaceae, Convolvulaceae, Euphorbiaceae, and Brassicaceae, respectively. The starch grain analysis in sediments and artifacts may verify or discard the prehispanic record of these tuber crops, as it happens with Chenopodiaceae–Amaranthaceae. Preliminary studies carried out in Boyo 2 resulted in important advances where hundreds of starch grains assigned to *Oxalis* sp. were identified in a notched and serrated working edge bone tool made of camelid scapula (Buc et al., 2016). Regarding *Solanum* cf. *tuberosum* and cf. *Ipomea batatas*, starch grains assigned to these taxa were recently identified in food residues from Quebrada Norte 7 pottery assemblage (López and Recalde, 2015).

## Conclusion

Palynological analysis is widely used as a proxy of ancient land cover and to infer prehistoric human activities from sediments if correct conditions are met (Craig et al., 2010; Fish, 1994; McLauchlan, 2003; Piperno, 1995). Here, the palynological study allowed the reconstruction of the vegetation associated with three open-air sites and two rockshelters, even when in Las Chacras 2 the post-depositional dynamic affected the reach of the results.

Late Prehispanic Period pollen assemblages were dominated by herbaceous plants commonly described as disturbance indicators consistent with cooler and drier conditions. Yet this is not the land cover predicted by the paleoclimatic proxies of increasing temperature, precipitation, and moisture during the ‘Medieval Warm Period’, when more potential for xerophytic forest growth was expected (Andreazzini et al., 2013; Carignano, 1999; Krapovickas and Tauber, 2016; Piovano et al., 2009; Silva et al., 2011). Moister conditions were reflected by fossil pollen assigned to Cyperaceae, Apiaceae, Sparganiaceae, Thyphaceae, and Potamogetonaceae, as well as faunal indicator of warm and humid conditions – that is, *Holochilus vulpinus*, *Necromys lasiurus*, *Oxymycterus rufus*, and *Euphractus sextintus* (Medina and Merino, 2012; Soibelzon et al., 2013). The presence of wood charcoal of *Sarcomphalus mistol*, *Prosopis* sp., and *A. caven* up from the modern treeline in Puesto La Esquina 1 also provides independent confirmation of this expectation (Medina and Merino, 2012).

Pollen and archaeological studies suggest that disturbance was not purely of natural origin and that prehispanic small-scale farming and other land-clearing activities must be taken into account. The disparity between the modern pollinic rain and fossil samples, discarding drier conditions and the contribution of extra-regional sources, correlates with the first evidence of low-level food production, demographic expansion, storage and increasing occupational redundancy of the group residing in the region at ca. 1500 yr BP. Thus, the disturbance was related to a new dimension of human occupation of the region by people who practiced flexible land-use and mixed subsistence strategy.

Chenopodiaceae–Amaranthaceae pollen data indicate that the late prehispanic groups not only adapted to the mountain landscape through economic and mobility strategies but also modified



it in a more extensive way than previously assumed. The late prehispanic people moved around the landscape to take advantage of both domesticated and wild resources. The repeated clearing of the forest for housing, farming, and/or other activities incidentally increased the on-site abundance of wild starchy-seeded annuals that constitute an important human food resource since ca. 3000 yr BP, enhancing the possibility of future reoccupations. So, the results also reflect a plant husbandry that involved cultigens and quasi-cultigens, rather than a simple exploitation of Chenopodiaceae–Amaranthaceae crops or wild stand. Moreover, the creation of open patches may have also favored the concentration of wild tree-fruit species such as *G. decorticans*, *S. mistol*, and *Prosopis* spp. that opportunistically propagate in modern bare areas (Rapport et al., 2009) and formed one of the basis of late prehispanic diet. Thus, the dynamic of base-camp occupation may have modified the surrounding land cover at evolutionary time scales, constituting another example of niche construction and ecological inheritance processes (Odling-Smee et al., 2003).

The results allow to assume that late prehispanic people even with simple technology contributed to modify the late-Holocene land cover, improving the conditions for future landscape reoccupation as well as the creation of ‘persistent places’ (Schlanger, 1992). This interpretation differs from most archaeological views of Late Prehispanic Period that have tended to attribute landscape changes to climate and considered small-scale societies as passive foragers exploiting the ecosystem (see Laguens and Bonnín, 2009).

The presented model shows that the modern Sierras of Córdoba land cover is not an anthropogenic artifact of land-use practices initiated after the European’s arrival in the sixteenth century AD as some ecologists have suggested (cf. Díaz et al., 1993; Silva et al., 2011). Pollen studies in archaeological sites challenge this viewpoint arguing that humans influence the structure and function of the environment since the first evidence of on-site farming at the Late Prehispanic Period (ca. 1500 yr BP). Certainly, the anthropogenic disturbance may not be an exclusively late-Holocene phenomenon and probably started when first Amerindian colonized the area (Renison et al., 2004). A well-documented example occurs during the late middle-Holocene, when a dramatic decrease in the high-ranked prey frequency was recorded in the archaeofaunal assemblages and interpreted as human overexploitation, co-directing subsequent cultural changes as the adoption of small-scale farming (Rivero and Medina, 2016). Even in the Sierras of Córdoba, the process of displacement of lithic raw material such as opal took place at 11,000 yr BP (Rivero, 2009) and produced its mark on the environment in the long term through the construction of a stone landscape where previously there were no high-quality rocks for tool knapping.

Thus, the further studies to understand the evolutionary dynamic of the mountain ecosystem should not disregard the changes brought by prehispanic humans, in particular by hunting, clearing activities, and their secondary consequences. The niche construction conception of evolution as a long-term behavioral accumulative process is also needed to be taken into account (Rivero and Medina, 2016). Although more high-resolution records are clearly required to answer the question definitively, several lines of evidence including faunal and archaeobotanical remains indicate that anthropogenic disturbance was the likely cause of some cultural and environmental changes that are seen in the archaeological record. The well-dated archaeological deposits, consequently, provide data for understanding the complexity of the evolutionary scenario and their changes across the time, as well as predicting future modification that Sierra Chaco environments may experience.

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## Notes

1. The control samples were horizontally recovered in a 1-m<sup>2</sup> grid at 0–2 cm below surface soil layer, previously litter clearance. It is assumed that they represent the average pollen composition of the area being sampled, providing a way to define modern floristic association and their relation to climate and anthropogenic influences (Pearsall, 2004; Piperno, 1995).
2. *Zea mays* pollen grains as described by Hall (2010) have not been found in fossil assemblages, even when maize starch grains, phytoliths, and macroremains were identified at C.Pun.39, Puesto La Esquina 1, and Boyo Paso 2 (Medina et al., 2016). Thus, maize farming was excluded from the palynological discussion.
3. ‘antiguamente sembraban quinua los indios de Cosquin’ (Archivo Histórico de la Provincia de Córdoba (AHPC), Escribanía I, Legajo 72, Expediente 2, f. 75v), ‘sembraban quinua y sapallos y mays’ (f. 82v), and ‘unos morteros que ycieron los dichos indios para moler quinua y mays’ (f. 80v).

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