



High Altitude Maize (*Zea Mays* L.) Cultivation and Endemism in the Lake Titicaca Basin

Staller John E*

Botanical Research Institute of Texas (BRIT), USA

Abstract

Botanists and plant biologists have long asserted maize (*Zea mays* L.) cannot be cultivated above 3,600 masl. Multidisciplinary evidence has documented an abundance of a particular variety of maize called *tunqu* by indigenous Aymara speaking populations and cultivated on terraces between 3810 to 4100 masl around the Copacabana Peninsula, in the Lake Titicaca Basin, Bolivia. This is the only known maize variety in the world cultivated above 3600 masl. The Titicaca Basin was transformed by various ancient cultures and civilizations and pre-Columbian landscape modifications such as raised fields and terraces. Such modifications were primarily geared to the cultivation of food crops. Multidisciplinary evidence indicates maize was and continues to be central to indigenous religious rituals and rites in the altiplano. Colonial accounts emphasize this maize was primarily consumed as a fermented intoxicant, maize beer (aqa, or chicha). It was considered sacred and also used for ritual offerings. Such practices and beliefs appear to have ancient origins and have been documented archaeologically with the Yaya Mama religious tradition (ca. 800 BCE). This maize variety has phenotypic characteristics unlike any other known landrace and these characteristics and its adaptation to such altitudes strongly suggest it may be endemic. The Andes are particularly well suited to studying the phenotypic diversity of plants, because the landscape is characterized by discrete ecological zones, which support specific suites of domesticated plants. The Titicaca Basin represents a unique microenvironment where evapotranspiration from the lake reduces the diurnal variation in temperatures enough to permit cultivation of maize. Its cultivation, preparation and consumption among indigenous cultures are analyzed as are its botanical and biological characteristics which distinguish this landrace and support the contention it is endemic.

Keywords

Andes, Maize, Botany, Ethnobotany, Archaeology, Ecology, Plant biology

Introduction

The Andes represent the second highest mountain range in the world and are characterized by complex ecologies and diverse environments, with biota specifically adapted to different regions, sides, and altitudes of the sierra (Figure 1). The Andean cordillera also includes unique microenvironments that affect the diversity and complexity of domesticated and wild plants and animals, and maize (*Zea mays* L.) is one such plant [1]. Archaeologists, ethnographers, botanists and plant biologists have maintained its cultivation is restricted to altitudes below 3200 masl [2-5]. Nevertheless, large-scale maize cultivation has occurred above 3600 masl in the altiplano of the Lake Titicaca Basin since prehistoric times [6-10]. Indigenous Andean communities (*ayullus*) along the southwestern part of the basin still herd alpacas and llamas. Since the introduction of foreign domesticated animals, they also raise sheep, cattle, pigs, donkeys, and chickens [9,11]. Native crops are cultivated by indigenous communities on terraces, often without irrigation, along with crops introduced during the Spanish conquest such as, fava beans, barley, and recently, onion (*Allium cepa*). Primary native food plants in the altiplano include, numerous varieties of quinoa (*kañiwa* or *juryra*) and potatoes (*ch'ugui*), oca (*uka* or *ulluku*), native lupin (*tarwi*), and a particular variety of maize exclusive to this region called *tunqu*

[10]. Native tubers are often freeze dried (*ch'unu*), and important to indigenous subsistence and their agricultural economy [11,12]. About 60% of the region is engaged in subsistence agriculture [13]. The western portion of the basin adjacent to Lake Titicaca around Juliaca and Puno, Peru is slightly colder than the Bolivian side of the basin, with higher diurnal variation in temperatures [11] (Figure 2).

Archaeological and ethnographic evidence has documented large-scale maize cultivation at c. 3810 to 4200 masl - the highest known cultivation in the world, primarily centered around the Copacabana Peninsula. Previous interdisciplinary research indicated indigenous communities in various regions of the basin cultivate high yields of a

***Corresponding author:** Staller John E, Research Associate, Botanical Research Institute of Texas (BRIT), Fort Worth, Texas, USA, Tel: 773-631-2644, E-mail: jstaller7@gmail.com

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maize variety called ‘*tunqu*’. Local *campesinos* consider this maize as ‘sacred’ and use it almost exclusively to make maize beer or *chicha* for ritual feasting, rites, and as offerings [7,9]. Multidisciplinary evidence presented here suggests the *tunqu* maize may represent an endemic variety, specifically adapted to the microenvironment of certain regions of the Titicaca Basin [1,11].

Evolution and Domestication of Maize

Plant domestication represents a process of evolutionary change

involving the genetics and biogeography of plant populations through human and natural selection. The domestication of plant species is generally perceived in the scientific literature as a process of evolutionary change involving the genetics of plants [1,14-18]. Genetic changes are in response to human influence or deliberate conscious selection, or artificial selection (unconscious selection), for certain favorable traits, or to management of plant reproduction and modification of the environment [1,17-22]. Domesticated plants such as maize are essentially cultural artifacts that would not exist in nature

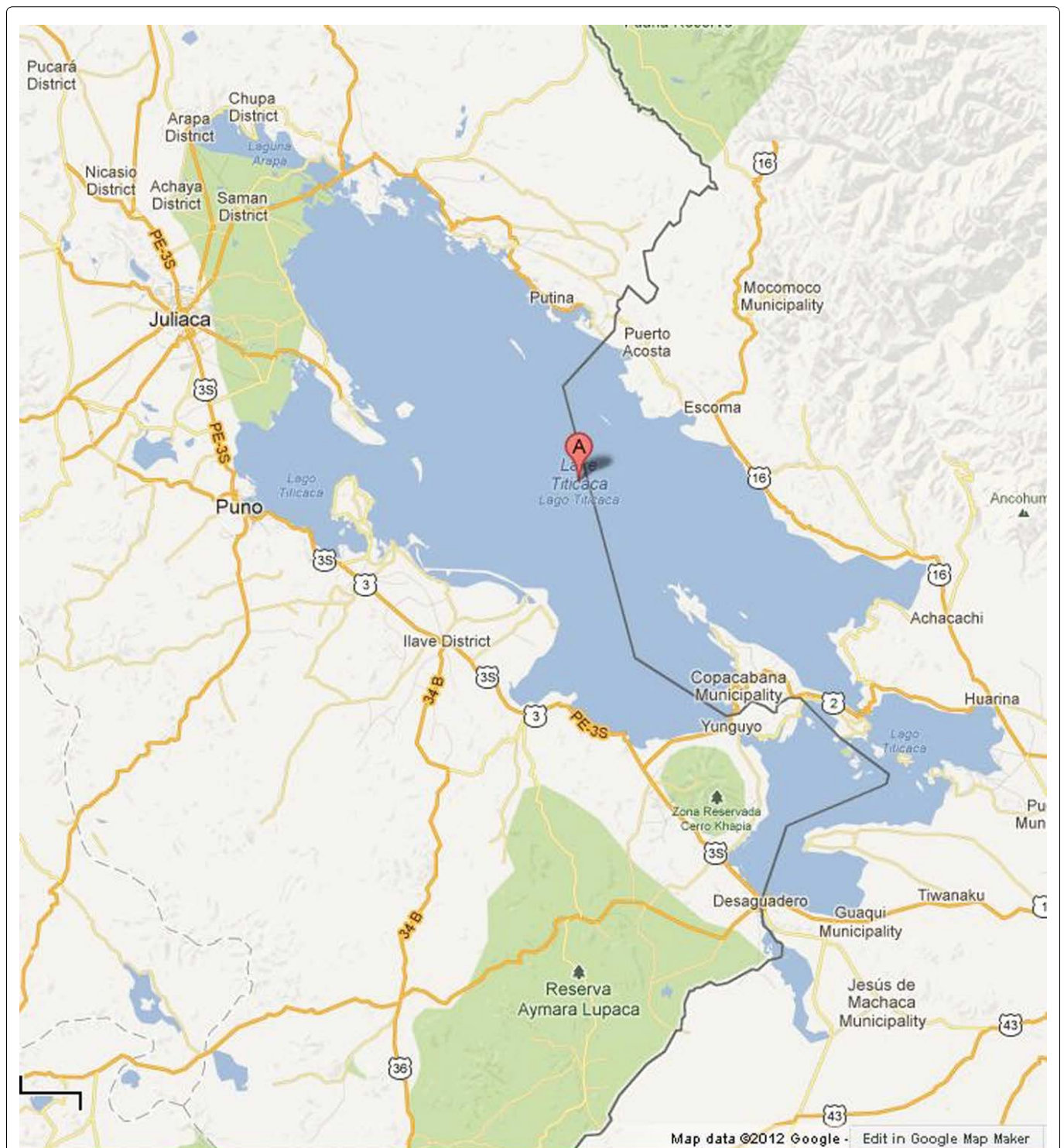


Figure 2: Map of Lake Titicaca Basin showing different cities and town around the various regions of the lake. The line marks the Peruvian and Bolivian political boundary, which passes across the middle of the lake. (Courtesy of Google Maps).

without human assistance, unlike teosinte, its wild predecessor and its various subspecies [21,22]. Human adaptation selects for these interrelationships because they provide strong selective advantages for both the plant(s) and human populations dependent upon them. The cultural importance, biogeography, phenotypic variability of early maize varieties in the New World has been the subject of considerable research and publications in the social, biological, and in recent years the molecular sciences.

Recent botanical, ethnobotanical, and DNA research have documented the domestication and spread of maize in increasing

detail [19,23-26]. Maize or corn (*Zea mays* L.) is monophyletic. Maize evolved from a single domestication event c. 7000 years ago, a direct descendant of an annual wild grass, teosinte (*Zea mays* ssp. *parviglumis*) native to the Balsas River drainage in southern Mexico [25,27]. The genus *Zea* includes cultivated maize (*Z. mays* ssp. *mays*) and the various subspecies of teosintes, classified by plant taxonomists as members of the grass family *Poaceae* [3,28]. The fruit of the genus *Poaceae* is a caryopsis or has the appearance of a seed with flowers usually arranged in spikelets with one or more florets further grouped into panicles or spikes (Figure 3). All taxa of *Zea* have a central spike

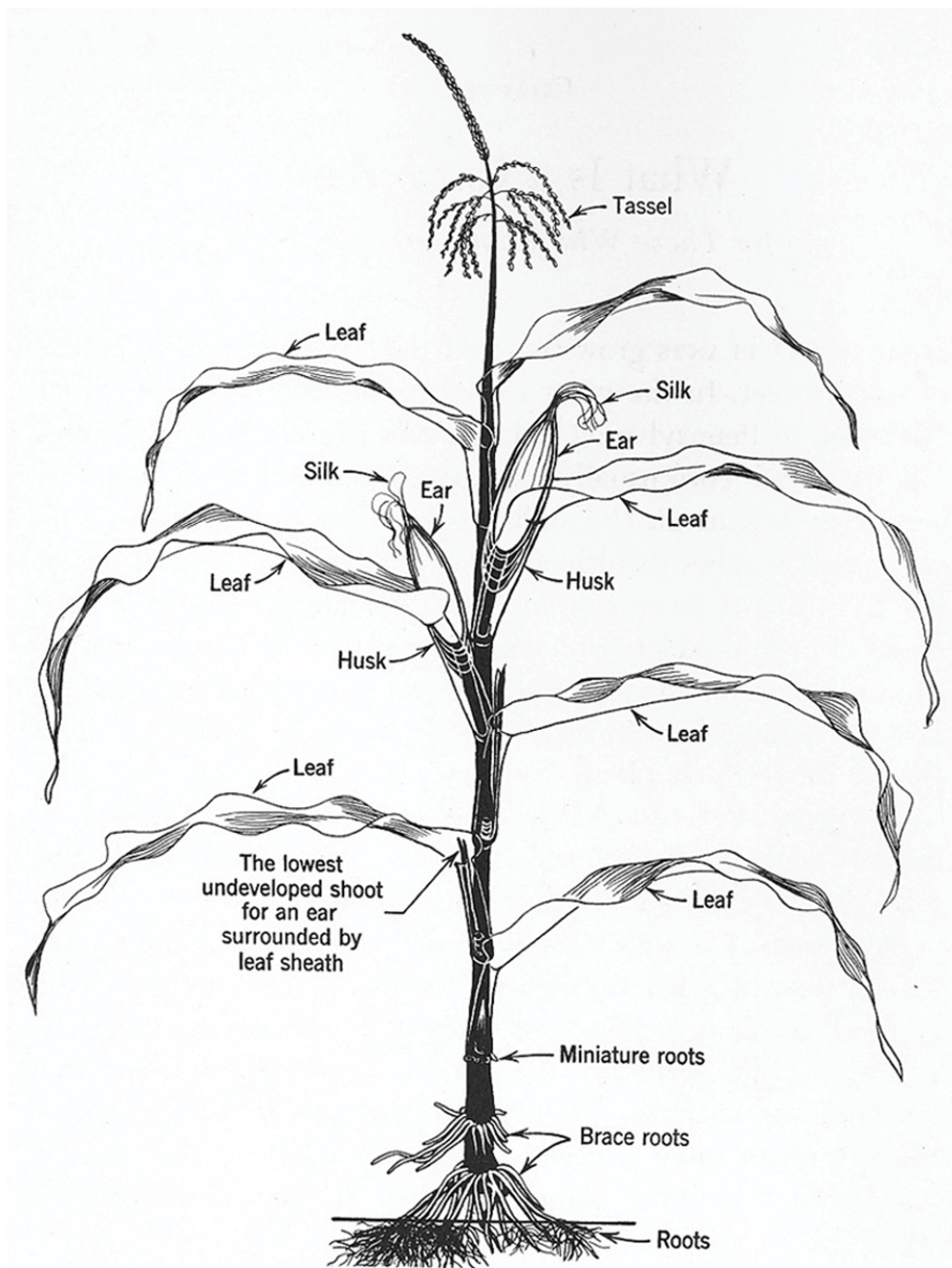


Figure 3: Maize and its constituent parts labeled. Maize tassels are distinguished from other wild grasses by their thick and highly condensed terminal spikes (with spikelets) and their slender and uncondensed lateral branches. (From Wallace and Brown 1956: Figure 1).

or terminal branch, a continuation of the central inflorescence axis [28,29]. Teosinte and maize both have male and female flowers on the same branch, and kernels “encased in a hard, leaf-like organ called a glume” is highly branched, with a male inflorescence (tassel) on its central branch and female inflorescences (ears or cobs) on auxiliary branches (Figure 4). What differentiates maize (*Zea mays* L.) from its wild predecessor teosinte (*Zea mays* ssp. *parviglumis*) is that it is totally depend upon humans for its survival, and biogeography [28]. Plant and molecular biologists perceive the domestication process as a gradual and fortuitous accumulation of genetic mutations that create a mutualism and interdependence between human populations, and target plant species and/or populations [1,18,30]. Evolutionary changes due to unconscious selection are initiated by changes in relationships between humans and a particular target species such as maize [21,30]. Selective pressures perceived in terms

of a causal relationship usually involve behavioral change toward a maize landrace; selecting certain traits to induce a genetic response, and ultimately morphological and phenotypic modifications [30]. In the case of maize, the ear and kernels provide the most reliable phenotypic traits classification of landraces and their the phylogenetic (historical) relationships [21,31-33]. Maize is highly mutagenic, kernel color and ear morphology are directly affected by wind pollen from maize cultivated in surrounding fields.

Research on maize DNA has proven most effective in establishing its origins [14,25]. Documentation of the maize genome made it possible for botanists and molecular scientists to directly document how domestication and cultivation affect the phylogeny of maize landraces [14,34]. Our current understanding of the bottleneck phenomenon, the phenotypic variation expressed by the different



Figure 4: The silk of the maize plant is a female element, while pollen is male. The silks are fertilized by wind pollen from tassels of other maize plants. (Courtesy of John Tuxill).



Figure 5: Maize Diversity. Popcorn landraces have been documented to be the earliest in the Andes. The cordillera has the greatest diversity of maize landraces in the world; this is related to human selection for particular traits and adaptation to the extreme environment. (Courtesy of the USDA/ Agricultural Research Service).

maize landraces through anagenesis and cladogenesis, has allowed research to more clearly understand and further explore why certain maize varieties are maintained while others disappear [14,15,30,35] (Figure 5).

Molecular biologists identified the existence of a Mendelian locus (*teosinte glume architecture tga1*) that controls the cupule and glume morphology of maize ears or cobs [23,24,36]. These data provide evidence to document the spread of various



Figure 6: The effects of the *tga1* locus on cob morphology on this variety from the terraces around Copacabana. (Courtesy of Robert G. Thompson).

landraces, as well as the role of human selection to its phenotypic characteristics and morphological traits. This single Mendelian locus (*tga1*) also controls several aspects of chaff morphology, both macroscopic and microscopic, including the deposition of silica such as phytoliths and epidermal cells [1,7,24]. Moreover, *tga1* also controls the induration, orientation, length, and shape of the chaff, and its pleiotropic effects suggest it represents a regulatory locus [23,24]. The diverse mosaic of maize varieties, high genetic diversity among landraces, are related in part to a founder effect, resulting from a population bottleneck followed by conscious selection for specific traits [14,26,30] (Figure 6).

Origins and Biogeography of Maize

Archaeological research on the origins of maize was critical to our understanding of the transition from hunting and gathering to agricultural economies [19,37-39]. Its domestication and spread through different regions of the New World is largely associated with the rise of pre-Columbian agriculture and its perceived importance as a staple to early agricultural economies [15,16,38,40-43]. However, evidence from early cave and rock shelters sites suggest teosinte fruitcases were not exploited for food, but rather for their stalks [17,37-39,41]. Macrobotanical evidence suggests teosinte was initially exploited for its stalk sugar, which was used as a condiment or for fermentation [44]. Several of these rock shelters and caves provided evident of quids or chewed maize stalks in the earliest stratigraphic layers [37-39,41,45]. Archaeological evidence indicates maize stalks were initially chewed to make intoxicants such as *pulque*, providing insight regarding maize biogeography to various parts of Mesoamerica and throughout the New World [1]. The earliest distinguishing characteristics separating fully domesticated maize from its wild progenitor teosinte at various rock shelters and caves is the glume architecture [19,46]. Thus the *tga1* locus controls cob size, row number, kernel shape and size primary phenotypic characteristics that define and differentiate different varieties of maize landraces [14,17,32,46] (Figure 6).

Direct AMS dates on the earliest maize in Latin America are relatively recent c. 5900 to 5450 B.C. [1,47,48]. Most associated ¹⁴C dates suggest an initial expansion dated to c. 7000-4500 B.C., and a subsequent expansion into the American SW at around 2000 B.P [1,49,50]. Systematic identification of maize varieties, as well as recent research in the Andes cordillera, provide clear evidence of the incredible mutability of maize and its ability to adapt to a whole host of environmental and climatic conditions [1] (Table 1). Despite its

early initial expansion maize does not become a primary economic staple in Mesoamerica and the Andes until several millennia later, c. 1500 to 1000 B.C. [1,41].

The recent multidisciplinary research has transformed previous paradigms regarding its origin, biogeography, phenotypic diversification. Food science is now challenging previous paradigms regarding its economic and cultural significance to complex sociocultural development. Data from stable carbon isotope research on ancient diets, have revised our understanding of its economic and dietary roles to Pre-Columbian Mesoamerica and the Andes, as well as other regions of the Americas [22,51-54].

Endemism, Environment, Species Diversity, and Climate

Endemism refers to species that are unique to a particular ecology, habitat or specific geographic location or region [55,56]. Endemic species are characterized by unique phenotypic characteristics, which distinguish such species from others of the same taxon. Physical, climatic, and biological factors contribute to endemism and endemic species are particularly likely to evolve in geographically and biologically distinct or isolated regions [56] (Figure 7). The greatest incidence of endemism in the Andes occurs in the Huancabamba Depression, northernmost highland Peru and southern highland Ecuador, because these regions represent the lowest part of the cordillera where both plant and animal species can move and spread to both sides of the cordillera [1,57]. The upper Amazon of Peru and Bolivia, and the Lake Titicaca Basin are also characterized by a high incidence of endemism [10,58,59]. The discrete ecological zones of the cordillera are characterized by specific suites of economic plants and animals. Transitional environments

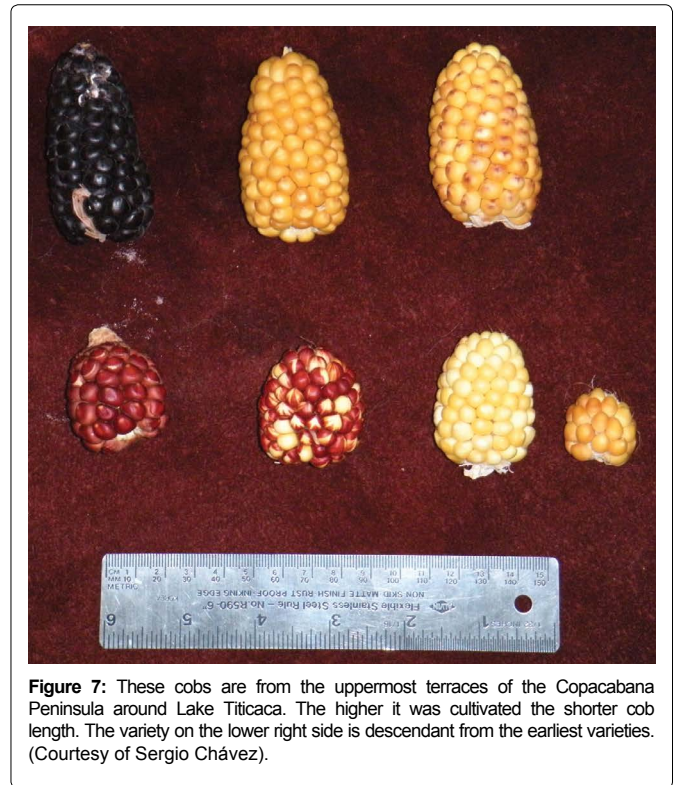


Figure 7: These cobs are from the uppermost terraces of the Copacabana Peninsula around Lake Titicaca. The higher it was cultivated the shorter cob length. The variety on the lower right side is descendant from the earliest varieties. (Courtesy of Sergio Chávez).

Table 1: Early AMS dates on macrobotanical maize samples. The table includes early dates from Mexico since they represent the chronological baseline for dated samples in other regions of the Neotropics and Western South America.

Country/Region	Site	Dated material	¹⁴ C method	¹⁴ C years B.P.	Sample ID no.	Reference
Mexico						
Oaxaca	Guilá Naquitz	Maize Cob	AMS	5420 ± 60	Beta-132511	[47]
Puebla	San Marcos Cave	Maize Cob	AMS	4700 ± 110	AA-3311	[100]
Puebla	El Riego Cave	Maize Cob	AMS	3850 ± 240	AA-52684	[15]
Puebla	Coxcatlan Cave	Maize Cob	AMS	3740 ± 60	AA-3313	(Table 1)
Tamaulipas	Romero's Cave	Maize Cob	AMS	3930 ± 50	Beta-85431	[101]
Tamaulipas	Valenzuela's Cave	Maize Cob	AMS	3890 ± 60	Beta-85433	[102]
Chiapas	San Carlos	Kernel	AMS	3365 ± 55	Beta-62911	[103,104]
Chihuahua	Cerro Juanaquena	Maize Cob	AMS	2980 ± 50	INS-3983	[105]
Tabasco	San Andres	Maize Cob	AMS	2565 ± 45	AA-33923	[106]
Sonora	La Playa	Maize	AMS	1885 ± 50	n/a	[107]
Ecuador/coast	Loma Alta	Kernels	AMS	3500	n/a	[108]
Ecuador/coast	Loma Alta	Carbonized Kernels	AMS	2490 ± 40	Beta-103315	[109]
Peru						
Northern highlands	Pancan	Maize Cob	Conventional	1500 ± 40	n/a	[110]
Trujillo/north coast	Paredones	Charred Husk	AMS	5900 ± 40	OS-86020	[48]
Trujillo/north coast	Paredones	Charred Maize	AMS	5584 ± 35	AA-86932	[48]
Trujillo/north coast	Paredones	Charred cob	AMS	4181 ± 34	AA-86934	[48]
Central Coast	Los Gavilanes	Maize Cob	AMS	2333 ± 35	AA-93181	[111]
North Central coast	Caballette	Maize Stalk	Conventional	2380 ± 40	GX-32724	[112,113]
Brazil/Minas Gerais	Peruaçu Valley	Maize Cob	AMS	990 ± 60	-	[114]
Argentina/Mendoza	Gruta del Indio	Maize	Conventional	2065 ± 40	GrN-5396	[115]
Catamarca/highlands	Punta de la Pena 4	Kernel	AMS	560 ± 50	UGA-15089	[110]
Chile/North Coast	Ramaditas	Maize Cob	AMS	2210 ± 55	GX-21725	[98]
	Guatacondo	Maize Cob	AMS	1865	UCLA-1698c	[98]
	Rixhasca	Kernel	AMS	1025	GX-21748	[98]
	Tiliviche 1-b	Maize Cob	AMS	920 ± 32	AA-56416	[98]

Note: Only the earliest macrobotanical dates are presented.

and ecologies, or what is categorized as an 'ecotone', also have a high incidence of endemism [1,57].

The pleiotropic effects suggest *tga1* represents the regulatory locus which makes the *tunqu* maize variety in the Copacabana peninsula truly distinct from all other known varieties of maize (Figure 8). This maize variety is endemic because its phenotypic characteristics are

specific to the Titicaca Basin, particularly around the Copacabana peninsula, where *tunqu* has been cultivated since prehistoric times [7,9]. The reduced diurnal variation in temperature caused by evapotranspiration of the lake creates a microenvironment which makes the cultivation of maize as well as other crops possible in such extreme altitudes (Figure 9).

Multidisciplinary research in the Peruvian and Bolivian Amazon have modelled the geographic distribution of numerous endemic plants and species between 1000-1500 masl [59]. However, the concept of endemism and identification of endemic species is largely dependent upon knowledge of the geographical range of a particular species. The Peruvian and Bolivian Amazon Basin is characterized by extreme biodiversity. However, the botanical and biological data with regard to the biogeography of various taxon are not well documented [58,60,61]. However, the phenotypic diversity and biogeography of maize have been extensively documented in the social, as well as botanical and biological sciences [1,14,15,32,34].

The Lake Titicaca basin has been a focus of considerable attention by researchers and its regions and islands are well defined and documented [62-66]. Maize cultivation was initially believed to be restricted to sheltered locations with northern exposure on the shores of the lake or the various islands [67-69], the terraces above Puno or the District of Chucuito overlooking the lake [2,70]. Archaeologists maintained maize had little economic importance in the region, and neglect to discuss the associated altitudes, varieties, or their phenotypic characteristics. Most emphasize its consumption as a vegetable or its ritual or ceremonial importance to the political economy [2,4,70].

Andean maize varieties cultivated above 3200 masl are largely a product of conscious selection of particular traits in combination with adaptation to the extreme environmental conditions [71].

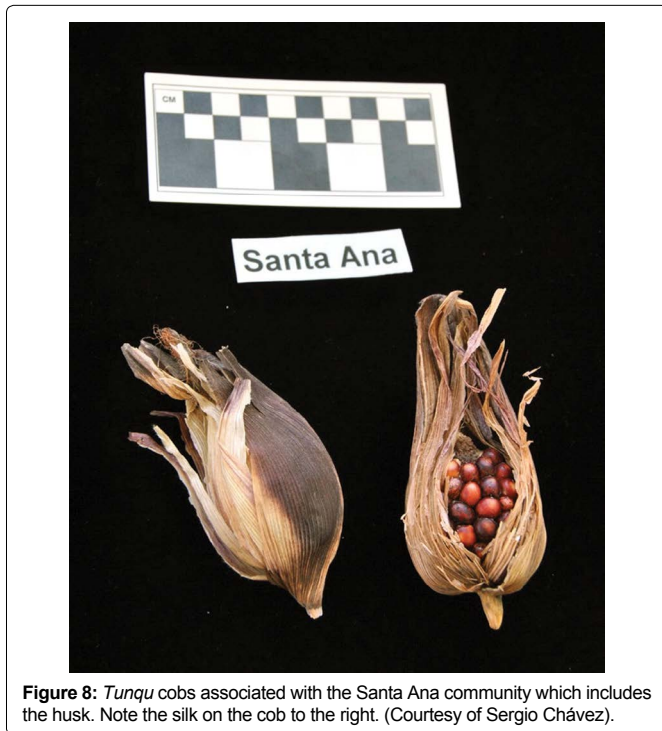


Figure 8: *Tunqu* cobs associated with the Santa Ana community which includes the husk. Note the silk on the cob to the right. (Courtesy of Sergio Chávez).



Figure 9: Terraces on the Isla del Sol or Island of the Sun. The Inca built an administrative center with storage facilities and maintained these terraces, which probably have much earlier origins. The evapotranspiration of the surrounding lake makes such large-scale cultivation possible. (Courtesy of Google Images).

Variation in maize varieties such as *tunqu* are a result of human selection and adaptation to micro environmental conditions created by the lake. This is particularly apparent on terraces around the Copacabana Peninsula, where *tunqu*, an endemic variety of maize grows in altitudes over 3800 to 4100 masl [1,7]. Its distinct phenotypic characteristics and restricted geographic distribution has only come to the attention of scholars in recent years, [7,9,10]. This may be related in part to its cultivation and consumption being restricted to indigenous communities in the basin.

The Lake Titicaca Basin straddles the border Peru and Bolivia, and the lake is the largest and highest navigable lake in the world (Figure 1 and Figure 2). The basin is situated in a high altitude plain or altiplano ranging c. 3800 and 4100 masl [9,72-75]. About 90% of the fish species in Lake Titicaca are endemic [76,77]. Overall, the altiplano is a harsh and difficult environment for the cultivation of many domesticated plants [78,79]. However, a significant decrease in diurnal temperature variation around the lake caused by evapotranspiration, creates a microenvironment in which various economic staple including maize been cultivated in these altitudes since ancient times [1,10]. The climate is classified as subtropical highland and cultivation is strongly affected by the semi-arid, and cold dry season cycle. Mean annual temperatures of between -3 °C to 10 °C, with slightly lower diurnal variability in and immediately around the lake in cities such as Copacabana, Bolivia and Puno, Peru (Table 2 and Table 3). Copacabana and Puno are both located beside the lake with average high temperatures of c. 15.3 °C (59.5 °F), and 18.5 °C (64.8 °F) and average low temperatures of 1.6 °C (33.1 °F) and 1.58 °C (32.6 °F) respectively. Average annual precipitation in these regions of the basin are between 580.7 mm (22.9 inches) and 669 mm (26.4 inches) (Table 2 and Table 3). The climate around Juliaca, Peru, which is situated in a higher altitude and whose climate is considered to be more characteristic of the basin as whole has average high temperatures of c. 17 °C (62.5 °F), while the average annual precipitation is around 580 mm (22.9 inches) (Table 4). Thus, the basin overall is more arid and characterized by slightly higher diurnal

variations in temperature. The subtropical highland climate around the basin is distinct because it is situated in the tropics, it is in one of the highest parts of the cordillera, and consequently has a markedly drier dry season. The thermo-regulation through evapotranspiration, albeit slight and subtle, appears to have dramatic consequences for diurnal temperature variations, climate, as well as the physical qualities of sedimentary deposits [11,80]. Evapotranspiration around the lake water reduces the diurnal temperature variation, by creating a microenvironment more amenable to cultivation [9,79,81]. The agricultural cycle generally spans from early December to April, and cultivation around the lake is totally dependent upon rainfall since the waters of Lake Titicaca are saline [9].

Maize and Andean Culture

The Lake Titicaca Basin essentially represents a built landscape transformed for cultivation over the millennia by various cultures and civilizations extending back to Initial Period [9,63,72]. Initially the archaeological evidence suggested maize was introduced to the Titicaca basin during the Middle Horizon Period by the Tiwanaku civilization. More recent research has identified maize at sites ranging from the Formative to Early Horizon Period [74,75,82]. However, food residues preserved on ancient Yaya Mama pottery, including 247 samples from Ch'isi, Qhot'a, Pata, Kusijata, Cundisa, and Qupakati, produced three AMS dates ranging between 800-460 B.C. associated with Yaya Mama religious tradition on the Copacabana Peninsula [7,9]. Archaeological and ethnographic evidence of agricultural terraces on the peninsula between 3810 to 4200 masl are said to have very ancient origins [7,9]. The basin was subsequently transformed by human engineering and landscape modifications geared to the cultivation of food crops [9]. Yaya Mama culture was egalitarian and non-centralized. The center has a series of temples complexes which played a major role to maintaining ethnic diversity, while at the same time engineer and coordinate widespread regional landscape modifications [6,7,9]. In contrast to the monumentality of Tiwanaku architecture, the Yaya Mama were organized into distinct *ayullus* or

Table 2: Climate in Copacabana, Bolivia, Lake Titicaca Basin. Copacabana is situated on the peninsula in the southern part of the lake basin. Like Puno it is situated directly along the shoreline and there are terrace constructions on all sides of the peninsula. These are believed to be the oldest terraces in the Titicaca Basin.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Average high °C (°F)	15° (59)	15° (59)	15° (59)	15° (59)	15° (59)	14° (57)	14° (57)	15° (59)	16° (61)	15° (59)	17° (63)	16° (61)	15.3 (59.5)
Average low °C (°F)	4° (39)	4° (39)	3° (37)	2° (36)	-2° (28)	-4° (25)	-4° (25)	-3° (27)	-1° (30)	2° (36)	2° (36)	4° (39)	1.6° (33.1)
Average precipitation mm (inches)	137.3 (5.406)	82.6 (3.25)	82.3 (3.24)	31.6 (1.244)	7.0 (0.276)	9.8 (0.386)	6.0 (0.236)	30.2 (1.189)	27.8 (1.094)	27.8 (1.567)	49.7 (1.957)	76.6 (3.016)	580.7 (22.863)

Table 3: Climate in Puno, Peru, Lake Titicaca Basin. Puno is situated along the western shores of the lake and has terrace construction along the shoreline as well as further up all facing the lake.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Average high °C (°F)	18° (64)	18° (64)	18° (64)	18° (64)	18° (64)	17° (63)	18° (64)	17° (63)	19° (66)	19° (66)	20° (68)	20° (68)	18.5° (64.8)
Average low °C (°F)	4° (39)	4° (39)	4° (39)	1° (34)	-2° (28)	-6° (21)	-6° (21)	-3° (27)	0° (32)	2° (36)	3° (37)	4° (39)	1.58° (32.6)
Average precipitation mm (inches)	160 (6.3)	115 (4.5)	134 (5.3)	65 (2.6)	5 (0.2)	3 (0.1)	0 (0)	9 (0.4)	22 (0.9)	39 (1.5)	30 (1.2)	87 (3.4)	669 (26.4)

Table 4: Climate in Juliaca, Peru, Lake Titicaca Basin. Juliaca is situated in the highest part of the cordillera and its climate is said to most closely reflect climatic conditions in the basin overall.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Average high °C (°F)	16.7° (62.1)	16.7° (62.1)	16.8° (61.7)	15° (62.2)	16.6° (61.9)	16° (60.8)	17° (60.8)	17° (62.6)	17.6° (63.7)	18.6° (65.5)	18.8° (65.8)	17.7° (63.9)	17.08 (62.76)
Average low °C (°F)	3.6° (38.5)	3.2° (38.3)	3.2° (37.8)	0.6° (33.1)	-3.8° (25.2)	-7° (19.4)	-7.5° (18.5)	-5.4° (22.3)	-1.4° (29.5)	0.3° (32.5)	1.5° (34.7)	3° (37.4)	-0.78 (30.6)
Average precipitation mm (inches)	133.3 (5.248)	108.7 (4.28)	98.5 (3.878)	43.3 (1.705)	9.9 (0.094)	3.1 (0.122)	2.4 (0.09)	5.8 (0.228)	22.1 (0.87)	41.1 (1.618)	55.3 (2.177)	85.9 (3.382)	580.7 (22.992)

communities, who subsequently cultivated *tunqu* on terraces around the lake for over three millennia [9,64,65,83].

Maize played a central role to the rise of Andean civilization because of its roles and importance to religious rituals and rites, rather than as a food staple. Ethnographic and ethnohistoric accounts state that it was so commonly consumed as beer (*aqha* or *chicha*) as to make a significant contribution to the diet [1,22,84,85]. The term for maize beer is '*chicha*' derived from the Nahuatl '*chichiya*', which means, "to become sour, bitter", in reference to the fermentation process [86]. In parts of Guatemala, the term "*chicha*" is still used by some Maya to refer to maize based fermented intoxicants or *pulque* [87]. The Spaniards spread the term to designate both alcoholic and non-alcoholic beverages made from various plants. The Aymara word for maize, *tunqu*, appears in the 1612 Aymara dictionary by Bertonio, but until recently, it has been rarely used in the literature. Quechua terms *runa simi* or *sara* are more prevalent, and both terms are still used by Aymara and Quechua speakers [1,86]. *Tunqu* is not mentioned in the 1608 Quichua dictionary of Gonzalez Holguin (1952 [1608]) [88]. Maize beer was central to fostering social alliances and was redistributed by various Andean polities as a form of reciprocity in exchange for corveé labor [4,84]. Inca territorial expansion was based in part upon large-scale maize production associated with widespread terrace construction. Such terrace constructions and maize cultivation largely involved *chicha* production, and when consumed as food, various landraces played a major role in Andean ethnic identity and regional political economies [4,5,84,85]. One of the earliest Andean locations for such large-scale terrace construction was the Copacabana Peninsula in the Lake Titicaca Basin [6,7,9].

Carl Sauer [1950: 494] [2] stated, "*The Spanish annalists give the impression that more of it was drunk and less eaten...*". The chronicler Cieza de León (1959 [1553]) [89] was particularly impressed by the

drinking powers of the indigenous Andeans and its importance to rituals, rites, and high status elite [90,91]. However, the first conquistador to mention maize cultivation in the Titicaca basin was Martin de Murúa (1987 [1590]:556) [92] who documented maize cultivation at 3650 masl near present day La Paz. The Bolivian altiplano was particularly important to the Spanish Crown and various Colonial governments because to the south around Potosi, Bolivia was Cerro Rico, which has the richest silver ore deposits in the Americas [89,91]. Potosi was also the location of the Spanish colonial mint, and chroniclers state that many thousands of indigenous people died from mercury poisoning working in the Cerro Rico silver mine [86].

Pre-Columbian Andean religions are inherently telluric, naturalistic and spatial. Their origins and creations from previous conditions or states particularly mythological emergence from a wild or natural state into the existing creation cycle [1,84-86]. Ethical order of the sacred landscape was manifest though the cultivation of valley bottomlands, terrace construction, channeling water into agricultural fields, and architectural modification of sacred places (Figure 10). Ritual offerings to *huacas* continue perpetuate the circulation of time and bring forth regeneration, fertility and fecundity of the earth among indigenous populations (Figure 11). The terrace construction was associated with the civilizing of the natural landscape and its people through the imposition of an ethical order [84-86]. Water is seen to flow through the earth into the underworld and into the sky in the form of the Milky Way [86]. The destinies of many Andean cultures was shaped by the manipulation of water, evident by customs such as ritual washings, ritual beverages, and the manipulation of irrigation technology. However, unlike the elaborate irrigation networks associated with the raised fields at nearby Tiwanaku, there is little evidence of irrigation technology in the Copacabana Peninsula since all of the cultivation associated with the terraces is dependent upon the coming rains [6,9,10].



Figure 10: Artificial terraces along the Copacabana Peninsula. These are the earliest terraces in the basin and appear to have their origins in the formative periods with the Yaya Mama religious tradition. (Courtesy of Sergio Chávez).



Figure 11: Endemic maize varieties in the Copacabana Peninsula region of the basin showing the viability in cob size and kernel shape associated with a community in Belem. Such factors are important to ethnic identity in Andean culture. (Courtesy of Sergio Chávez).

The cultivation of the *tunqu* maize in this region of the Andes cordillera was initially brought to the attention of scientists and scholars by George Squier (1973 [1877]:331, 341) [93] who noted that on the Copacabana peninsula and some islands of the lake, the maize stalks were, “scarcely three feet high” and the cobs were “no longer than one’s finger” and “closely covered with compact vitreous grains” (Figure 12). The cultivation of the small-sized maize growing on lower terraces on some of the island around the peninsula was confirmed some 20 years later [94]. Although not specified in these later accounts, it appears from the ethnographic and archaeological evidence *tunqu* maize was consumed both as food source and had important ritual and ceremonial significance [9].

Maize Phenotypic Diversity in the Titicaca Basin

The Andes are particularly well suited to studying the phenotypic diversity of plants, because the discrete ecological zones support specific suites of economic plants. Cultural modifications to the landscape vary in time, but stone-faced terraces particularly on the slopes and hills of the Copacabana Peninsula and those around Puno which also are constructed along the shoreline of Lake Titicaca appear to have an ancient history (Figure 10). The monumental terraces reflect a uniform style and technology of construction [7,9]. In other part of the basin, raised field agriculture was also an adaptive response to the altitude and cold temperatures characterizing the altiplano, as was cultivation on *qochas* or artificial depressions (*suka qullu*) and artificially irrigated pastures or *bofedales* to herd llamas and alpacas [63,74,79,93,95]. Dates for raised field cultivation and these other landscape modifications range from c. A.D. 300 to 1000 [63,64,74].

The stone-faced terraces around Copacabana range in width from one on steep slopes to several meters wide, and in some areas, preserved to a height of three meters [9]. Their distribution is continuous around the peninsula, including the islands of the Sun and Moon and several other islands south of the peninsula, only interrupted by rock outcrops and steep hills (*ibid.*). Subsistence



Figure 12: The *tunqu* maize stalk in this examples stand a little higher than a meter. Maize cultivation along the peninsula is totally dependent upon rainfall, which is higher on the southeastern part of the lake than around Puno. This had an important role in early cultivation of maize in this region of the basin. (Courtesy of Sergio Chávez).

agriculture is critical to adaptation to such altitudes and most indigenous communities are engaged in cultivation of food crops [13]. In fact, quinoa was originally domesticated c. 3000 B.C. in this region, and this is reflected in the genetic diversity of its varieties [8,96].

Over 52 communities on the Copacabana Peninsula cultivate maize annually, from lake level to as high as 4100 masl, taking advantage of the microenvironmental conditions of the lake basin to meet subsistence and surplus needs. Early research described distinct varieties of maize for Peru and Bolivia primarily on the basis of phenotypic characteristics [97], recently such descriptions include genotypic characteristics [8]. Early maize classifications restricted to phenotypic characteristics of the cobs clearly indicated that this variety is endemic and exclusive to this geographical location, its climatic variability, flexibility.

There is a long history of cross pollination of *tunqu* varieties with other regions of the Andes. The pre-Columbian maize consumed in the basin by the Wari and Tiwanaku cultures was brought in from lower parts of the eastern cordillera and the coast the context of traditional Andean political economies [4]. The Inca cultivated and stored maize at administrative centers in and around Cochabamba, and all along the eastern cordillera that they commonly cross-pollinated with coastal varieties, particularly around Moquegua and northern coastal Chile [98]. Recent documentation of the maize genome has directly documented the interrelations of various landraces over space and time [14,25,26,33]. Cutler (1946:281-282) [99] illustrates examples of altiplano maize ears from the shores of Lake Titicaca (Bolivia) that closely resemble the small and medium *tunqu* described here. Significantly, he noted that there was little or no change when planted using irrigation in Cochabamba, implying that the phenotypic characteristics of this variety are a product of both human and natural selection and geographically restricted to the basin, an important characteristic of endemism.

This *tunqu* maize variety is characterized by small ears and cobs measuring 3.5-5 cm in length (Figure 13). They stand about a half a

meter in height (Figure 12). Varieties which grow in the lower terraces closer to the lake generally have larger kernels and cobs and are taller; medium to large cobs range 6-9 cm to 10-13 cm long respectively, and stand between 80 to 165 cm in height (Figure 6). Pointed popcorn varieties called *p'asangalla* have adapted to the highest elevations and their cobs are between 5-10 cm long (Figure 14). Large cob varieties which grow in the extreme altitudes are generally varieties which were cross pollinated to attain larger kernels and cobs with varieties in lower elevations [1,10]. Weatherwax (1954:62) [29] reported the existence of "pygmy" maize varieties standing about 60 cm high in some areas of this region. However, this may be a product of recent cross pollination with varieties from lower elevations. In the highest elevations a stalk usually produces only one cob, while in the lower elevations they have two or sometimes three cobs per stalk [9]. The cobs have different shapes; those from the highest elevations are rounder, pointed popcorns more slender, basically because they are longer, and usually lack straight rows. Row numbers vary depending if or with what varieties they were cross pollinated from 10 to 14 for the smallest cobs, from 13 to 14 for larger cobs, and the greatest range is with the popcorn varieties which have 5-12 rows. Kernel color is a primary phenotypic characteristic among indigenous communities for differentiating distinct maize varieties, and this is related to their culture, because kernel color and shape has associations to ethnic identity. Indigenous communities even differentiate multicolored kernels from those of a particular color. Pointed popcorn (*p'asangalla*) varieties are usually a bright yellow or white (Figure 13). According to the chroniclers, kernel color was also important among the Inca as it relates to their uses in rituals, rites, curing, and *chicha* manufacture [1,85].

Until recently, most investigators have neglected to take into account the subsistence potential of cultivating maize in the basin. The Titicaca Basin is largely believed to lack the potential for economically significant maize cultivation. Overall, the altiplano environment is harsh and difficult for the cultivation of certain plants.

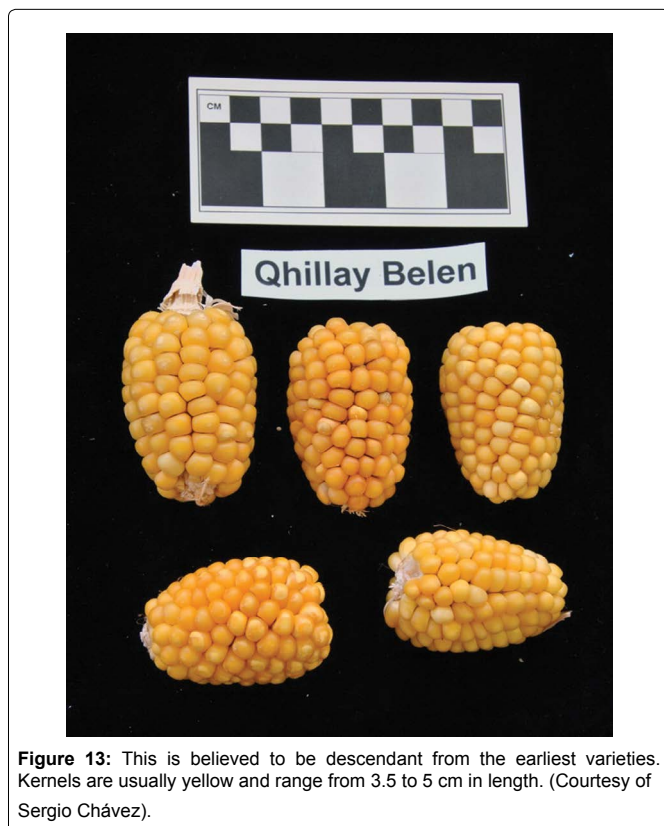


Figure 13: This is believed to be descendant from the earliest varieties. Kernels are usually yellow and range from 3.5 to 5 cm in length. (Courtesy of Sergio Chávez).

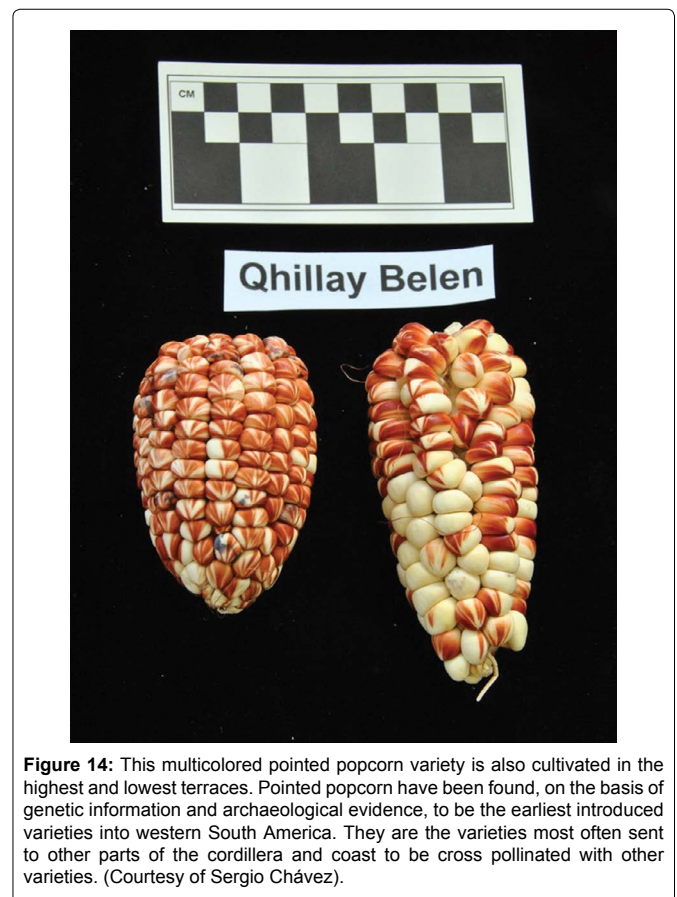


Figure 14: This multicolored pointed popcorn variety is also cultivated in the highest and lowest terraces. Pointed popcorn have been found, on the basis of genetic information and archaeological evidence, to be the earliest introduced varieties into western South America. They are the varieties most often sent to other parts of the cordillera and coast to be cross pollinated with other varieties. (Courtesy of Sergio Chávez).

However, decreased diurnal temperature variation around the lake caused by evapotranspiration, creates a microenvironment in which maize has been cultivated in these altitudes since Colonial times and extend well into the pre-Columbian past.

Summary and Conclusions

The ecology and environment in the Titicaca Basin is related to the micro-environmental conditions created by the lake. It is the evapotranspiration of the lake that increase the nighttime temperatures just enough to create the conditions for maize cultivation at these extreme altitudes. Both natural and human selection make these endemic landraces distinct in different regions of the Lake Titicaca Basin. The phenotypic characteristics of *tunqu* maize is distinct, cobs are smaller in length, more bulbous in shape with smaller kernels and fewer row numbers than those cultivated in other regions of the Andes. Whenever maize landraces from the coast or the eastern cordillera are brought to this region and cross-pollinated with maize landraces from they are also phenotypically transformed by adapting to the extreme altitude. Pointed popcorns brought to this region from the Chilean or Peruvian coast or the eastern Andes around Cochabamba all revert in their phenotypic characteristics within one or two growing cycles. In terms of size and cob shape they become smaller and the kernels more rounded, similar to the *tunqu* landraces. However, they maintain or change their kernel color and shape to varying degrees depending upon what other varieties are cultivated nearby. Adaptation to periodic drought results in tiny cobs, what were once considered by scholars to be “wild” corn (Copacabana 2, 13). These have been identified in northern Chile and southern coastal Peru, indicating altiplano maize from the basin was and continues to be cross pollinated with other regions. It is obvious from the phenotypic characteristics and the fact that exotic landraces respond in similar ways to the microenvironmental conditions around the lake that natural selection is producing varieties, which are truly unique to the species and geographic region and are therefore endemic.

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