9 Quinoa (*Chenopodium quinoa*)

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9.1 Brief History of Crop

Quinoa (*Chenopodium quinoa* Willd.) is a domesticated staple food in Andean South America (Fig. 1). It is principally a grain crop, harvested and consumed in a manner similar to that for cereal grains, although its leaves are also used as a potherb. Quinoa was domesticated by ancient Andean civilizations in the region surrounding the Bolivian and Peruvian Altiplano (high plain). Gandarillas (1968) examined genetic diversity in quinoa landraces and found that the greatest diversity is native to an area between Cuzco, Peru and Potosí, Bolivia, with the largest number of landraces located in the area of the Altiplano surrounding Lake Titicaca in Bolivia and Peru. According to Gandarillas (1974) and the National Research Council (1989), there is a consensus that quinoa's center of origin is in the Andean Altiplano and that the area of ancient cultivation extends from Andean Altiplano to regions of Bolivia, Peru, Ecuador, Northern

Fig. 1. Quinoa (*Chenopodium quinoa*) cv. Real, growing under traditional cultivation practices (groups of plants spaced 1×1 m) near the Salar de Uyuni, Bolivia at ca. 3656 m above sea level

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Chile, and Colombia. The oldest archeological remains of domesticated quinoa date to 5000 BC (Tapia 1979).

Anciently, quinoa was known by a number of names in local languages. Pulgar-Vidal (1954) mentioned that people of the Chibcha (Bogota) culture called quinoa "suba" or "supha," the Tiahuancotas (Bolivia) called it "jupha," and the inhabitants of the Atacama desert (currently in Chile) knew it by the name "dahue." León (1964) wrote that the names "quinua" and "quinoa" were used in Bolivia, Peru, Ecuador, Argentina, and Chile.

Although it was and is the most widely cultivated grain chenopod, quinoa is not the only domesticated species of *Chenopodium*. Cañihua (*C. pallidicaule*) was domesticated in the same region as quinoa but is not as productive, nor is it as highly domesticated as quinoa. Because of its extreme frost tolerance, cañihua is adapted to high-altitude environments greater than 4000 m above sea level and is still cultivated in these areas (Galwey 1995). Huazontle (*C. berlandieri* subsp. *nuttalliae*) was domesticated in Mexico, where it served anciently as a seed crop and potherb but is currently cultivated principally for its leaves and immature inflorescence. A domesticated form of *C. album* is cultivated in the Himalayas as a seed grain and potherb (Partap and Kapoor 1985).

At the time of the Spanish conquest of the Inca Empire in 1532, quinoa, potatoes, and maize were the principal staple foods in Andean South America, with quinoa cultivation extending slightly beyond the region occupied by the Incas (Galwey 1995; Cusack 1984; Risi and Galwey 1984). Following the conquest of the Incas, quinoa cultivation precipitously declined with displacement by crops preferred by the conquistadores. According to Cusack (1984), quinoa held such a high position in Inca culture and religious ceremonies that the Spanish conquistadores may have actively suppressed its cultivation in an effort to eradicate traditional Inca religious rites. Furthermore, quinoa was not adopted as a crop by European settlers in South America or in Europe, as were the new world crops of maize and potatoes. Quinoa cultivation continued to decline into modern times as rural farmers migrated to urban centers, incentives were paid to farmers to plant barley, faba beans, and oats instead of quinoa, and increased dependence on imported food discouraged quinoa cultivation. According to Galwey (1995), the area of world quinoa cultivation had declined to ca. 39,000 ha by 1975.

In the mid-1970s, the exceptional nutritional characteristics of quinoa were discovered and its popularity began to increase. Andean countries established small, but effective, breeding programs, and several new varieties were released. Efforts to collect diverse landraces to prevent genetic erosion resulted in national quinoa germplasm banks in many Andean countries, the largest being in Bolivia and Peru. Quinoa's major use is still as a staple crop for subsistence farmers in rural regions of the Andes. However, a new international market for organically grown quinoa is increasing, creating a demand for export quinoa production in South America and some commercial production outside of South America.

9.2 Botanical Description

Wilson (1990) described in detail the botanical classification of cultivated *Chenopodium* species. The genus *Chenopodium* is in the family Amaranthaceae, although it was formerly in the family Chenopodiaceae. Phylogenic revision has merged the Amaranthaceae and Chenopodiaceae under the name Amaranthaceae (Angiosperm Phylogeny Group 1998). The domesticated *Chenopodium* species are classified in two subsections: Cellulata and Leiosperma. Leiosperma includes the South American species cañihua (*C. pallidculale*) and the Eurasian species group *C. album*. Quinoa (*C. quinoa*) and huazontle (*C. berlandieri* subsp. *nuttalliae*) are members of the subsection Cellulata. Most significantly for scientists interested in quinoa improvement, there is a dearth of published information on the breeding value of related *Chenopodium* species. Another serious problem concerns the taxonomy of this complex genus; for example, *C. album* has been used as a "convenient taxonomic receptacle" (Wilson 1980), although this species might actually form a complex of diploids, tetraploids, and hexaploids (Table 1). It should be noted that a few of quinoa's close relatives have been domesticated, such that they could potentially be developed into productive cultivars in their own right, either as vegetable or as seed crops. These include *C. album* (fat hen or lambsquarters) in Eurasia, hexaploid *C. giganteum* (khan or bithua) in the highlands of South and East Asia (Partap et al. 1998),

Table 1. *Chenopodium* species with their 2n chromosome number, 45S and 5S rRNA locus number (as determined by FISH to laminar meristem chromosomes) and orgins. Adapted with permission from Kolano 2004

Species	Chromosome #	Origin	rRNA loci		Ref.
			45S	5S	
C. album L.	18	Eurasia (wide spread)	1	2	1, 3, 4, 6
	36		1	3	
	54		2	4	
C. ambrosioides L.	32	N. America	1	1	1, 4, 6
C. aristatum L.	18	Eurasia	1	1	1, 4, 6
C. berlandieri subsp *nuttalliae* 'Huauzontle'	36	N. America	2	3	1, 4
C. berlandieri subsp *nuttalliae* 'Quelite'	36	N. America	1	3	1, 4
C. berlandieri Moq.	36	N. America	1	2	1, 4
C. bonus-henricus L.	36	Eurasia	2	2	1, 4
C. botrys L.	18, 36	Eurasia	1	1	1, 4, 6
C. bushianum Aellen	36, 54	N. America (midwest)	2	4	1, 3, 4
C. capitatum (L.) Ascher	18	N. America	1	1	1, 4, 6
C. ficifolium Smith	18	Asia	2	2	1, 3, 4
C. foliosum (Moench) Asch.	18	Eurasia	2	1	1, 4
C. giganteum D. Don	54	Eurasia	2	4	2, 3, 4
C. glaucum L.	18, 36	Asia/N. America	1	1	1, 3, 4, 6
C. hybridum L.	18	Eurasia/N. America	1	1	1, 3, 4
C. murale L.	18	Eurasia	1	1	1, 3, 4, 6
C. neomexicanum Stand.	18	N. America (southwest)	1	1	1
C. pallidicaule Aellen	18	S. America (Andes)	1	1	4
C. petiolare Kunth	36, 54	S. America (Andes)	2	4	4, 5
C. polyspermum L.	18	Eurasia	1	1	1, 3, 4
C. quinoa Willd.	36	S. America (Andes)	1	2	3, 4
C. rubrum L.	18, 36	Europe/N. America	1	2	1, 4, 6
C. schraderianum Schult.	18	Africa/Asia (southwest)	1	1	1, 4
C. sp. 'Silvestre Salinas'	18	S. America (Andes)	1	1	4
C. strictum Roth.	36	Eurasia	1	2	1, 3
C. vulvaria L.	18	Europe/N. America	1	1	1, 3, 4

References: (1) Clemants and Mosyakin 2003, (2) Zhu et al. 2003, (3) Rahiminejad and Gornall 2004, (4) Kolano 2004, (5) Wilson 1980, (6) Welsh et al. 2003

tetraploid *C. berlandieri* subsp. *nuttalliae* (huauzontle, chia, or quelite) in Mesoamerica (Wilson and Heiser 1979), and diploid *C. pallidicaule* (cañahua) in the Andes.

Quinoa is apparently an allotetraploid, although most genetic markers, both morphological and molecular, segregate in a typical disomic Mendelian fashion (Maughan et al. 2004; Ward 2000, 2001; Bonifacio 1990; Simmonds 1971; Gandarillas 1968). The chromosome number is 2n = 36. The basic chromosome number for all known species in the genus and most species in this family is x = 9, and quinoa has numerous wild relatives with chromosome numbers of 2n = 18, 36, and 54, indicative of its apparent tetraploid origin (Table 1). The haploid genome of quinoa (n = 18) is ca. 967 million nucleotide pairs, as determined by flow cytometry, and is thus relatively small compared to most plant species (Maughan et al. 2004).

Genetically and ecologically, quinoa varieties can be separated into two economically important subgroups: Andean ecotypes adapted to the high-altitude environments of the Altiplano regions of Bolivia and Peru, and coastal ecotypes adapted to the humid, disease-prone coastal lowlands of Chile and Ecuador (Wilson 1988 a). Recently, several modern, improved varieties have been released, predominantly within the Andean subgroup. These varieties are genetically uniform inbred lines, and they display substantially higher yields than their landrace counterparts (Bonifacio and Gandarillas 1992; Bonifacio et al. 2003).

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