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Origin, Production and Utilization of Pseudocereals

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1.1 Quinoa – *Chenopodium quinoa* Willd (Amaranthaceae)

1.1.1 Introduction

The Andean region, an area inhabited originally by the Inca and Tiwanaku civilizations, is considered the centre of origin of *Chenopodium quinoa* Willd. Native to South America, it is an annual crop with several varieties and it was an important ingredient in the diet of many pre-Hispanic people. Traditional production areas are located in Peru – in Cajamarca, Callejón de Huaylas, Mantaro Valley, Andahuaylas, Cusco and Puno (high plateau); Bolivia – in the high plateau of La Paz, Oruro and Potosi and in the inter-Andean valleys of Cochabamba, Chuquisaca, Potosi and Tarija; and Argentina – in Jujuy, Salta and in the Calchaquí Valleys in Tucumán. It is also produced in Colombia, Ecuador and in the Chilean High Plateau (Barriga *et al.*, 1994).

Given its agronomic versatility, quinoa could be produced in regions where the population has no access to other protein sources. The plant adapts well to different agro-ecological soils and climate zones and is a water-efficient crop; it survives under low soil-moisture conditions. The nutritional properties of this crop, the plant's possible uses and the fact that it provides an alternative solution to nutrition problems render quinoa production promising. Nowadays, quinoa is grown not only in the traditional production areas mentioned above but in the United States, Canada, Italy, France, England, Sweden, Denmark, the Netherlands and in Africa.

1.1.2 Origin and History

Archaeological findings show that quinoa was a species commonly used by the ancient Andean cultures. Fruiting branches and loose grain have been found in different regions of Peru and in the Arica coastal area (Chile). Seeds have been found in native burial sites in Chile – in Tarapacá, Calama and in the Calchaquí-Diaguite region. In the New Continent, the Spanish found *colcas* (warehouses) where the natives stored their food and large amounts of quinoa. Quinoa, as well as *kañiwa* (*Chenopodium pallidicaule* Aellen) and other edible plants such as *kiwicha Amaranthus caudatus Linn*, were largely consumed by the Andean inhabitants.

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Heisser and Nelson (1974) pointed out that the archaeological findings in Peru and Argentina date back to the beginning of the Christian era. Accordingly, quinoa is one of the oldest crops in the Andean region, having been grown for approximately 7000 years (Jacobsen, 2013). The Tiahuanaku and Inca cultures played a major role in its domestication and preservation.

In 1586, Ulloa Mogollón mentioned the use of quinoa by the Collaguas in Bolivia. Quinoa was widely grown in the valleys in the north of Chile. In 1558, Cortés Hogea found quinoa crops in Chiloe Island. In 1583, Pedro Sotelo observed its existence in Argentina, in the Calchaquí Valley and in Córdoba (Tapia, 2013). Quinoa is a species with a wide-distribution multiple-diversification centre of origin. Its greater diversity and genetic variation took place on the shores of Lake Titicaca. According to Lescano (1994), today quinoa is distributed in the entire Andean region, from Colombia to the north of Argentina and Chile. A quinoa group was found in the region of Concepción, which is located at sea level. The geographical distribution of quinoa ranges from latitude 5° N in the South of Colombia to latitude 43° S in the IX Region of Chile, and from altitudes that go from sea level by the Chilean Sea up to 4000 m in the Peruvian and Bolivian High Plateau. The diversity of quinoa has been associated with five ecotypes: high plateau (Peru and Bolivia), inter-Andean valleys (Colombia, Ecuador and Peru), salt flats (Bolivia, Chile, and Argentina), warm valleys (Yungas, Bolivia) and coastal zone, lowlands (Chile). The plant's germplasm is associated with subcentres of diversity, considered as descendants of a central gene pool of the domesticated varieties around the Lake Titicaca basin. Toro (1971) studied quinoa from the Puno and Cuzco High Plateau and established a relation between crop age and its domestication and the usage of expressions of Quechuan (*Kinua*) and Aymara origin (*jupha* and *jiura*). Those terms are evidence of quinoa domestication by the Aymara and Quechuan people.

According to Wilson (1990), *Chenopodium hircinun* is included among the possible quinoa descendants, which evolved and domesticated the quinoa as we know it nowadays. There are four *Chenopodium* species related to quinoa, distributed in the south of the Andes, which are progenitors from which the modern quinoa varieties evolved: *C. carnosolum, C. hircinum, C. incisum, C. petiolare* (Mujica and Canahua, 1989). Originally, the Bolivian Southern High Plateau was identified as the quinoa genetic diversity centre (Gandarillas, 1979). Then, Christensen *et al*. (2007) worked with molecular approaches and simple sequence repeat (SSR) microsatellites, and suggested that the quinoa genetic diversity centre was the central Andean High Plateau from Peru to Bolivia. He indicated that the possible entry point of the Ecuadorian accession was the High Plateau from Peru to Bolivia. The molecular data showed the Ecuadorian and Argentine limited diversity of the Ecuadorian and Argentine quinoa germplasm. This may result from the small number of available samples and the limited germplasm conservation *in situ* in those areas. The information obtained confirmed that the possible entry point of the Ecuadorian accession was the plateau from Peru to Bolivia. Christensen *et al*. (2007) also stated that Argentine varieties had their origin in the northern Chilean plateau and in the southern coastal Chilean zones. This proves that Chilean quinoa is similar to its Bolivian counterpart, found in the southern high plateau. The genetic analysis led to the conclusion that quinoa has existed as two different gene pools:

- Quinoa from the Andean high plateau with the associated weeds complex (quinoa *ajara* or *ashpa*) *Chenopodium quinoa* variety *Milleanum* Aellen, known as *Chenopodium quinoa* variety *melanospermum* Hunziker.
- Coastal quinoa from the centre of Chile and south lowlands.

According to recent information, based on microsatellites and concerning quinoa diversity from the Argentine northeast (Costa Tártara *et al.*, 2012), a greater quinoa diversity is found in the Andean foothills and the east subtropical lowlands that surround Gran Chaco and the Pampa. This emphasizes possible germplasm movement patterns of old and modern quinoa in the region of Bolivia-Argentina-Chile. Molecular evidence suggests that genetic erosion has been affected by four events (Jellen *et al.*, 2011). The first might have been produced when two quinoa diploid descendants hybridized. The second one was when quinoa was domesticated from its tetraploid wild relatives through several cycles of seeds and crop exchange in new zones and climates. The third event might have occurred during the Spanish conquest, when quinoa was established as food for the indigenous communities (Cusack, 1984). The fourth event might have been caused by human migration from rural areas high in the Andes to urban centres. The countryside was therefore abandoned and the quinoa germplasm was lost (Fuentes *et al.*, 2012).

1.1.3 Botanical Characteristics / Species / Varieties

1.1.3.1 Species / Varieties

The *Chenopodium* section contains four subsections: Cellulata, Leiosperma, Undata and Grossefoveata:

- The Cellulata, alveolate pericarp pattern, 2n = 4x = 36, which includes *Chenopodium quinoa* Willd and *Chenopodium, berlandieri* ssp. *nutalliae*, and its domesticated and wild relatives *Chenopodium quinoa* ssp. *melanospermum* and *Chenopodium hircinum*, respectively.
- Leiosperma, smooth grains: *Chenopodium pallidicaule* Aellen (2n = 2x = 18). Wild quinoa has developed through an adaptation process in three areas:
  - South America: *C. hircinum* and *C. philippianum* as bridge species, with relatives (progenitors) of quinoa.
  - Northeast America: *C. bushianum* and *C. macrocalycium*.
  - Northwest America: *C. berlandieri*.
- Undata, *C. murale*, 2n = 2x = 18.
- Grossefoveata includes wild species of worldwide distribution (Giusti, 1970).

1.1.3.2 Botanical Description

Chenopodium quinoa is an annual herbaceous plant that develops in an erect position and has a pivotal deep and highly branched root system (Figure 1.1a). The stem may be branched or unbranched (Figures 1.1b and 1.1c), striated or channelled, green or red, with variable height depending on the genotype, climate and soil fertility. The stem typically reaches to between 0.5 and 1.5 m in height, but it may reach up to 2.5 m height in the inter-Andean valleys. Leaves are simple, smooth and pinnately veined with alternate phyllotaxes (Figure 1.1d).

The lamina is polymorphic rhomboid triangular in shape, 3–15 cm in length, with variable colours from red and purple, to yellow. Flowers are small, sessile and disposed in glomerulus (Figure 1.1e). The perianth has five tepaloid segments.

The androecium is composed of five stamens, short filaments bearing basifixed anthers. The gynaecium has two to three feathery stigmas. Three types of flowers are typically observed: female, hermaphrodite and androsterile, which may be autogamous

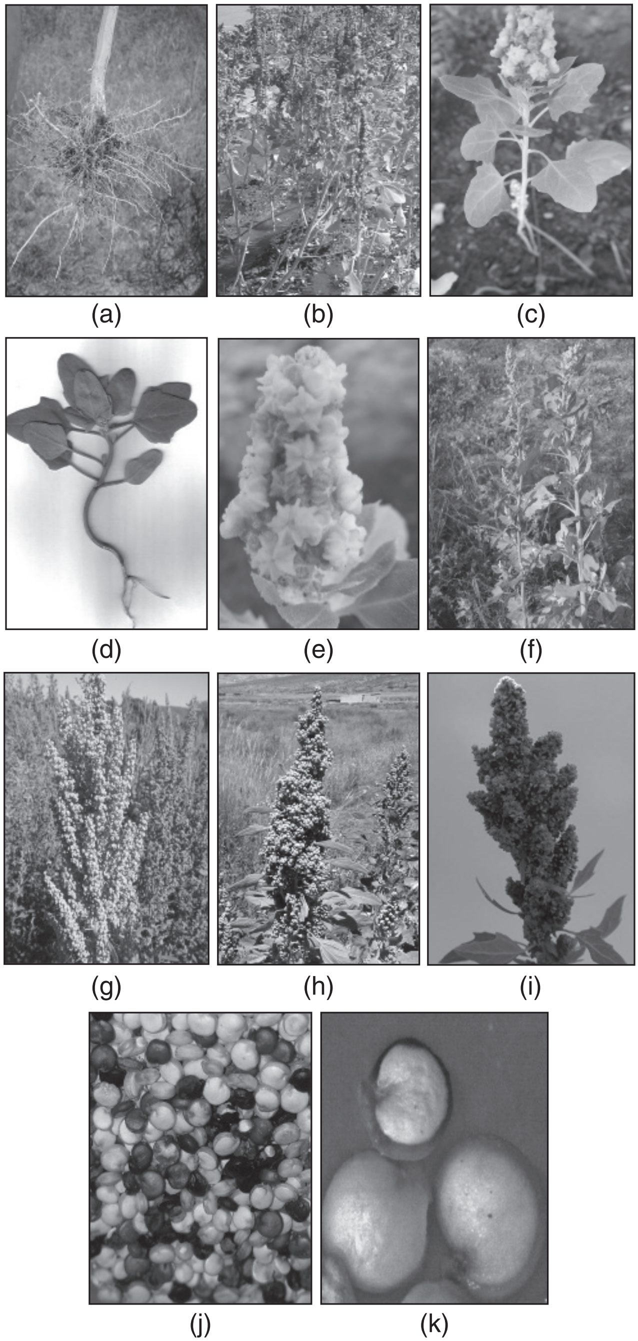

Figure 1.1 Development of quinoa plant: (a) taproot branched; (b) stem branched; (c) stem unbranched; (d) simple leaves; (e) small flowers; (f) panicle in training; (g) panicle amaranthiform; (h) compact panicle ; (i) mature panicle; (j) quinoa seeds; (k) seed. (*See color plate section for the color representation of this figure.*)

or allogamous and are typically arranged in panicles (Heisser and Nelson, 1974). Figure 1f shows a panicle in training. The panicle is made up of a central axis, secondary and tertiary branches and pedicels that support the glomerulus; it may be amaranthiform (Figures 1.1g) or compact (Figure 1.1h), with intermediate formations. The panicle's physiological maturity shows in Figure 1.1(i). The fruit is an indehiscent achene derived from a superior unilocular ovary, and it is cylindrical-lenticular in shape. The ventral part of the achene has a scar from the insertion of the fruit in the floral receptacle. The membranous perianth covers the achene, which easily detaches from the plant. The seed corresponds to the campylotropous type; the embryo is peripheral and has a basal body (Figures 1.1j and k). The areas of food reserves in seeds are: perisperm, a peripheral embryo and a one to two-cell layered endosperm surrounding the hypocotyl-radicle axis of the embryo.

Starch grains occupy at the cells of the perisperm, while the lipid bodies, protein bodies with globoid crystals of phytin, and proplastids with deposits of phytoferritin, are the storage components of the cells of the endosperm and embryo tissues. These globoid crystals contain phosphor, potassium and magnesium (Prego *et al.*, 1998). The quinoa seeds measure 1.5 to 2.5 mm in diameter. The episperm has four layers. There is an outer layer, which is rough and fragile – this contains the saponin. The second layer is narrow and smooth. The third layer is yellow, thin and opaque. The fourth layer is translucent and comprises a single stratum of cells. The embryo is formed of two cotyledons. The radicle is gemmule and curved with peripheral layers enveloping the perisperm. The perisperm is white in colour and serves as a compartment for nutrient storage.

1.1.4 Cultivation

1.1.4.1 Growth and Development

Phenological phases of the quinoa crop are readily recognized. Mujica and Quillahuaman (1989) has proposed 12 stages:

1) *Emergence:* 7–10 days after sowing, the cotyledons are visible above soil surface.
2) *Two true leaves:* 15–20 days after sowing; the epicotyl grows upward and gives rise to true rhomboid leaves with alternate philotaxis.
3) *Four true leaves:* 25–30 days after sowing; cotyledon leaves; two true leaves and the second pair of leaves is growing.
4) *Six true leaves:* 35–45 days after sowing. Three pairs of leaves are visible; alternate philotaxis. The cotyledon leaves will turn yellow.
5) *Branching with eight true leaves:* 45–50 days after sowing; the cotyledon leaves will abscise and fall. Inflorescence develops protected by leaves, which cover the panicle.
6) *Panicle initiation:* 55–60 days after sowing, inflorescence emerges from the shoot apical meristem, surrounded by numerous small leaves, which cover three-quarters of its surface. Basal leaves will turn yellow and the stem will become thick and long.
7) *Panicle formation:* 65–70 days after sowing, inflorescence emerges above the leaves and the glomerulus, at the base of which the flower buds are found.
8) *Beginning of flowering:* 75–80 days after sowing, the apical hermaphrodite flower will open, and stamens will be seen standing separately.
9) *Anthesis:* 90–100 days after sowing, 50% of the flowers will be open in the morning until midday. Then, they will close in the evening. The lower leaves will abscise and fall.

10) *Milky grain stage:* 100–130 days after sowing, the fruit is formed and, when pressed, a milky white fluid appears.
11) *Dough grain stage:* 130–160 days after sowing, the fruit present a dough-like texture when pressed.
12) *Physiological maturity:* 160–180 days after sowing, the fruit exhibits resistance when pressed. Leaves have turned yellow and this is followed by defoliation.

1.1.4.2 Climatic Requirements

Due to its wide genetic diversity, the quinoa plant has the ability to adapt to different environments. It can be grown in desert, hot and dry, cold and dry, mild and rainy climates, on high plateaus and in high Andean areas. The plant readily proliferates at temperatures between 15 °C and 20 °C, and can resist from 38 °C to −8 °C. Temperatures above 38 °C may cause flower abortion and senescence of stigmas and stamens. The plant also grows in high plateaus with 40% humidity, and in very wet regions of Chile. It can tolerate soil water deficit but a supply of 200–250 mm of annual rainfall ensures good development.

Photoperiod and radiation. The different genotypes may adapt to short-day length or long-day length, or be neutral, in relation to light conditions. In the South American Andes (Figure 1.2a), the quinoa plant responds well to a 12 daylight photoperiod. Radiation regulates crop distribution and reaches extreme values in high areas (Frere *et al.*, 1975).

1.1.4.3 Soil and Crop Management

Soil characteristics. The ideal soil for optimum growth should be well drained, preferably of loamy texture and with organic matter. The plant requires nitrogen and calcium, a small amount of potassium and phosphorus. It also grows well in sandy-loam, sandy or clay-loam soils with the essential nutrients for proper crop development. The plant tolerates a wide range of soil pH, growing well at pH 9 as well as in acid soils at pH 4.5. However, the quinoa plant prefers soils with near-neutral pH (Mujica *et al.*, 1997). The quinoa plant is generally not tolerant to flooded soils. Young plants are particularly sensitive to excessive humidity.

The plant displays fair tolerance to salinity. The critical period starts with germination. Jacobsen *et al.* (1997) assessed salt tolerance and observed a stimulation of the germination rate at low salt concentrations. When salt concentrations were increased to 350 mM, germination rate decreased. At a salt concentration of 700 mM, germination rate was so low that it could be regarded as the limit for salt tolerance.

Genotypes differ according to their tolerance to extreme soil salinity.

The Bolivian southern high plateau has soils of volcanic origin. The presence of considerable amounts of volcanic ash contributes to lower density and higher water holding and phosphate fixation capacity. These clay minerals in the soil retain and exchange cations, anions and water.

Water requirements. In both the Bolivian southern Altiplano and northwestern Argentina, technologies are applied to store water and genotypes resistant to water deficit conditions are grown. Moisture equivalent as a measure of the field capacity of the soil exceeds the amount of water needed for commercial quinoa production. Producers typically forecast high yields in dry years, and the opposite occurs for rainy years. In Peru's coastal region, the quinoa plant grows in deserts and sandy soils that have a field capacity of around 9%. In the Peruvian high plateau, where clay-loam soils are the rule, field capacity reaches up to 22%. In the south of Chile, the *Mapuches* produce the quinoa with around 2000 mm of annual rainfall, but specific genotypes that are adapted to the region are grown. Irrigation may be applied by simple gravity (e.g. furrow irrigation, flooding), dripping or sprinkler irrigation systems.

Traditional tillage is practised in the Altiplano and the inter-Andean valleys. The labour is carried out with manual tools (Figure 1.2b), including *tankan*, to prepare the soil; *taquiza* or *liukana*, to sow in holes; *azadon*, to harvest the crops, and *huaktana*, to conduct the threshing.

Mechanized tillage. A disc plough pulled by tractors was introduced as a tool to stir, loosen, and aerate the soil, and increase humidity and water storage. In the medium term, negative results of this practice were observed: the structure was lost and became compacted, drainage capacity, water infiltration, oxygenation and organic matter decreased. The soil was eroded and loss of soil fertility occurred. Radicular development of the plant decreased and yields dropped. The disc plough turned over the upper layer of the soil; small humus particles were exposed to the wind, and soil degradation took place. Consequently, a technological change in the soil preparation brought about the use of a plough called *Qhulliir* (Aimará).

Preparation of the block. Proper soil conditions include the slope or the terrain, good, fertile soil and the absence of flooding. If the previous crop was *Solanum tuberosum* L. (i.e. potato) or any kind of grass, manure must be incorporated, so that nutrients are available for the following rotation. Sandy soils, with low organic matter contents, benefit from a nitrogen, phosphorus, and potassium application, according to the needs and projected yields.

A mouldboard plough is typically employed for soil preparation. The machine works by burying weeds and the remnants of the previous crop. Then, a harrow is run in crossed passes for destroying and breaking up the soil capillarity and retaining rainfall water. In this case, the implement must be a double-action disc harrow with sharp edge discs and rigid arms. The equipment called *Qhulliri* is used today. The machine avoids soil erosion but it cannot be used in abrupt or pronounced slopes. Tillage preserves soil structure, thereby avoiding mixing or turning over of the soil. In addition, natural cover crops remain on the surface and erosion is prevented. This tool with fixed teeth loosens the soil; its blades cut the weed and a horizontal shovel levels the field surface.

Traditional sowing. In the dry southern Altiplano, sowing is conducted in holes by a special tool. This work is carried out with a *taquiza*, which produces a space of 1.20 m between the holes and the furrows, and 10 to 15 cm of depth. The holes are filled with a mixture of seeds and manure, and then the soil is packed down. When the seeds germinate, only four plants are left in each hole. Three kilogrammes of seeds per hectare are sown. This system works in dry, cold, arid and saline soil environments. In the inter-Andean valleys, sowing is practised in furrows 0.5 m apart. Six to 8 kg of seeds per hectare are placed in rows.

Mechanized sowing. Sowing is carried out depending on environmental conditions, field capacity moisture and the genotype characteristics. In Jujuy, Argentina, direct sowing takes place on irrigated soil in mid-February. In the Calchaqui Valleys, Salta, Argentina, the land is sown from October to December, based on rainfall. Sowing is done in rows. The spacing of 0.40 to 0.80 m between furrows depends on cultivar, and 8 to 10 kg of seeds per hectare are sown. In Salta, Argentina, vegetable seeders (Figure 1.2c) are used. Furrows are 0.50 m apart. In large plots, fine grain seeders have been adapted (Figure 1.2d). The spacing between adjacent furrows ranges from 0.70 to 0.80 m. Seeds should be sown up to 2 cm deep.

Cultural labour. In direct sowing, thinning is used to remove weak or debilitated plants. Weed control is either manual or mechanical. No herbicides are used. When sowing is conducted late, weeds compete with the crop and should be managed by hand-pulling them or using cultivators.

Irrigation. In the Andean region, crops typically rely only on rainfall. In the north of Argentina, the block is irrigated 3 or 4 days before sowing but, from that moment onwards, irrigation frequency will depend on the region and on water availability. The plant will require more water once it begins flowering and setting the fruit crop. Then, irrigation frequencies are reduced towards maturity.

Earthling up. When the plant reaches 0.50 to 0.70 cm high, mounds of soil are drawn up around the stem to allow the plant to continue growing upright once the panicles have developed. The weeds are removed either manually or mechanically.

Fertilization. Fertilization plans for the quinoa plant have to account for nitrogen, phosphorus and potassium needs. Potassium is generally not necessary, as South American soils are rich in potassium. A recommended fertilization formula is equivalent to 80-40-0. In sandy soils with low percentages of organic matter, the formula to be applied is 240-200-80 (Mujica *et al.*, 1997).

Harvest and postharvest. The timing of harvest depends on cultivar, soils characteristics, temperature and humidity. At the onset of ripening, leaves turn into yellow or reddish tones and the fruits develop from the inflorescence, which can be seen as the perianth opens (Figure 1.2e). This process is an indicator of physiological ripeness (Aroni, 2005). The leaves will abscise and fall. Fruit detachment indicates that fruits are ripe and thus ready for harvest. Ripening is verified by gently stroking the panicle, and if grains fall, the harvest must start shortly. Harvest is best practised in the early morning to avoid grain loss.

Under the traditional growing scheme, the ripe panicles are chosen from each furrow or row and the selected plant is pulled and shaken to remove the soil, or is cut with a hoe or a sickle 15 cm above the ground. String trimmers are also used to cut the panicles. The rest of the plant is incorporated as organic matter to the soil. For the same process, wheat combine harvesters adapted for this kind of harvest are used in Salta and Jujuy, northern Argentina (Figure 1.2f). After harvest, the panicles are arranged in piles or stacks forming arches to facilitate grain drying. The panicles are ordered into elongated or round mounds, all of them towards the same direction. When the panicles stand in a circle, inflorescences are placed in the centre. Then they are protected with straw or plastic to avoid loss of humidity. Panicles are left in this position, and, subsequently, after 7 to 15 days, they are threshed. In traditional threshing, the panicles are placed on a blanket, and beaten with an instrument called *huajtana*, a tillage tool from the Inca; then they are aired to separate the grains, which are exposed to the sun for 8 hours to decrease humidity to 12%. Cleaning is done with sieves, which classify the grains as follows: a top-quality grain should have a diameter larger than 1.8 mm and a lesser quality product grain should have a diameter smaller than 1.8 mm. There are threshers that combine the actions of cutting, threshing and airing. Clean grains are packed in polypropylene bags, stored in clean, dry and ventilated areas and placed on pallets at least 15 cm above the ground.

1.1.4.4 Diseases

Mildew. The agent causing mildew is *Peronospora farinosa* f. sp. Chenopodii, an oomycete in the family of Peronosporaceae and an obligate biotrophic parasite. Mildew attacks the entire plant, causes defoliation and affects fruit growth and development.

Figure 1.2 Quinoa cultivation, harvest and diseases: (a) quinoa in the South American Andes; (b) manual tools; (c) vegetable seeders; (d) fine grain seeders; (e) grain maturation; (f) harvest; (g) mildew; (h) abrupt leaf fall. (*See color plate section for the color representation of this figure.*)

The fungus develops optimally in humid environments and produces damage on lower leaves (Figure 1.2g). Then, it spreads to the upper ones. Pale yellow or reddish spots of all shapes and sizes in the upper surface may be observed. The purple-grey mycelium is typically observed in the lower surface of the leaves, followed by abrupt leaf fall (Figure 1.2h). Other symptoms include dwarfism, defoliation and reduction of yield under severe attacks can result in total crop loss (Ortiz *et al.*, 1976). Waterlogging should be avoided, as humidity provides a favourable environment for mildew development. It is important to check the presence of piercing and sucking insects (such as aphids) that transmit the infection. Some practical tips to deal with this disease successfully are crop rotation, cultural practices to diminish soil humidity and the use of resistant cultivars or genotypes. The application of copper sulfate is considered an effective preventive measure.

Leaf spot. The agent causing leaf spots is the fungus *Ascochyta hyalospora*, which affects leaves and stems. Such a fungus causes round, sunken spots and dark edges. It is transmitted by infected seeds and plant waste. The fungus cannot grow on the soil surface or survive when the vegetable matter has decomposed. It can be eliminated with a 3- or 4-year crop rotation.

Bacterial spot. The bacterium *Pseudomonas* reaches the leaves due to rain, wind, farm tools and seeds. Infection occurs at sites where humidity levels are high. The bacterium penetrate the stems and leaves through wounds produced by soil tilling or by insects. At the beginning of the infection, irregular water-soaked spots appear on leaves and then they get darker and necrotized, provoking serious lesions. Pycnidia are seen as black dots in the core. To prevent this bacterial infection, it is recommended to use healthy seed and resistant cultivars.

Pests. The quinoa plant ecotypes with a high saponin content are usually not attacked by insects. In addition to this, the high saponin ecotypes act like trap crops for nematodes attacking other rotation crops. The quinoa plant can also be affected by the *Eurysacca quinoae* Povolny moth, typical for the Andean region of South America. There are several species, such as *Eurysacca media* Povolny, *E. melanocampta* Meyrick and the *ticona* complex*: Copitarsia turbata* H.S., *Feltia* sp., *Heliothis titicaquensis* and *Spodoptera* sp. (Saravia and Quispe, 2005), which can cause reductions in yields ranging from 5% to 67%. *Eurysacca melanocampta* Meyrick, develops two generations in the crop, thus the control should be focused on the first stages. First-generation larvae excavate and feed themselves from the parenchyma of the leaves and developing inflorescences. Second-generation larvae affect panicles, destroying milky and ripe grains. This pest has predators and parasitoids that keep natural control: *Copidosoma koehleri* Blanchard, *Dolichostoma* sp., and *Copitarsia turbata* H.S. (Lepidoptera, *Noctuidae*). Such control is done during soil preparation with the tillage that destroys the pupae. The coleopteran *Calosoma* sp. is a predator of the larvae early stages. Contact insecticide with low residual effect can be applied, if necessary.

1.1.5 World Production of Quinoa

In 2012, 102 745 ha were cultivated with quinoa around the world, producing 82 510 tons. Peru and Bolivia are the main producers of quinoa, followed by Ecuador, which usually produces lower volumes (see Table 1.1). The three Andean countries, Bolivia, Peru and Ecuador have taken over the worldwide market. Growth rate of regional

Table 1.1 World production of quinoa.

Year	Country	Production tons	Surface ha	Yield kg/ha
2012	Bolivia	37 500	63 300	595
2012	Peru	44 210	38 495	1161
2012	Ecuador	800	1250	640
Total		82 510 ton	103 045 ha	

Source: Agrofood Division – FAOstat database.

exports have not shown a steady patterns. For example, in the first 10 years, sales increased four times, whereas from 2002 to 2012, sales increased 39 times. The production increased, but the average yield did not. In 2004, the total production of the three countries reached 52 326 ton; in 2012, it was 82 510 ton. The cultivated area in 2004 was 67 243 ha; in 2012, 103 045 ha. Average yield remained steady. In 2004: 771 kg/ha; in 2012: 795 kg/ha.

1.2 Amaranth – *Amaranthus hypochondriacus* L., *Amaranthus cruentus* L., and *Amaranthus caudatus* L. (Amaranthaceae)

1.2.1 Introduction

Amaranthus hypochondriacus L., *Amaranthus cruentus* L., and *Amaranthus caudatus* L., known as amaranths, are grown for grain in tropical regions of Africa, Central and South America and Southeast Asia (especially in India) as well as in warm regions of North America. In America, the producing countries are the United States, Mexico, Guatemala, Ecuador, Peru, Bolivia and, to a lesser extent, Argentina. In the 1980s, these species were rediscovered as promising food crops for food security due to their resistance and tolerance to biotic (pests and diseases) and abiotic (temperature and drought) factors and due to the high nutritional value of seeds.

1.2.2 Origin and History

The three amaranth grain species are annual herbaceous plants domesticated in prehistoric times in the high tropical and subtropical lands of America (Sauer, 1976). Archaeological findings in Tehuacán, Puebla, Mexico show that A. *cruentus* was already cultivated over 4000 years BC, and *A. hypochondriacus* was grown about 500 years AD (Sauer, 1976; Jacobsen and Mujica, 2003). They reached their maximum use when grown by the Aztecs in the valley of Anáhuac. In the fifteenth century, Arizona Indians also grew *A. hypochondriacus*. The earliest archaeological record of *A. caudatus* was found in the north of Argentina (Salta) dating back 2000 years, in an urn, which also contained flowers and pale seeds of amaranth, maize, bean and henopodium (Hunziker and Planchuelo, 1971). Spanish reporters highlighted the nutritional, cultural and religious significance these pseudocereals possessed among pre-Columbian inhabitants. The crop was believed to be sacred in Mexican cultures and its cultivation practices also had a special nomenclature (Itúrbide and Gispert, 1992). During the conquest there were several factors that acted synergistically to reduce the cultivation of amaranth (Sauer, 1976). Among those factors, it is worth mentioning its replacement by other species of grain introduced from the Old World, a lack of appreciation and religious reasons (Itúrbide and Gispert, 1992).

Sauer (1967) put forward two hypotheses about the origin of amaranth, according to the geographical distribution of its wild relatives, the current cultivated area and their morphological features. Sauer's first hypothesis stated that the three cultivated species might have developed from the domestication of one single species. After a succession of hybridization events with wild subgenus species, other cultivated species arose. Sauer (1967) speculated that *Amaranthus hybridus* gave rise to *A. cruentus*. Then, in the first hybridization event, *A. cruentus* crossed with wild *A. powelli* forming *A. hypochondriacus*. Additionally, he speculated that *A. cruentus* crossed in a second hybridization event with an unknown wild amaranth, giving rise to *A. caudatus*. His second hypothesis suggested that the species may have evolved independently from three different wild species, and was domesticated in both parts of the continent. In this sense, the author proposed that *A. powelli* gave rise to *A. hypochondriacus* for grain crop selection within the current crop area in North America. *A. cruentus* originated from the south of Mexico or Guatemala, in the area of its possible progenitor (*A. hybridus*). Lastly, *A. caudatus* derived from *Amaranthus quitensis* domestication in the Andes.

Recently, Kietlinski *et al.* (2014) have used microsatellites and a more comprehensive sampling of the subgenus wild relatives to understand the phylogenetic relationships of the cultivated species and the relationship between them and the *A. hybridus* complex species. Results from his studies confirm that *A. quitensis* belongs to a different species from *A. hybridus* and it is not the direct progenitor of *A. caudatus*. However, the two of them appear to be hybridizing to some degree in areas where their distribution overlap. *A. hybridus* may consist of two cryptic species or of a single highly variant species from which the three grain amaranths arose. As regards relationship between cultivation and domestication events, he suggested that there is a close phylogenetic relationship between *A. hypochondriacus* and *A. caudatus*, although they are geographically separated. According to this relationship, he proposed two hypotheses for the origin of *A. hypochondriacus* and *A. caudatus*. The first hypothesis refers to a single domestication event occurring in Mesoamerica or the Andes in which *A. hybridus* was followed by geographic divergence. The second hypothesis consists of a dual linage domestication, in which *A. hybridus* lineage, with a broad distribution, was domesticated independently from Mesoamerica to the Andes. Finally, he pointed out that *A. cruentus* may have originated from a secondary distribution in the geographical area of *A. hybridus* across Guatemala and Central Mexico because this is a more distinct species and has a great genetic variability.

1.2.3 Botanical Characteristics / Species / Varieties

It is estimated that there are about 21 germplasm collections worldwide, and the most important ones are stored in the American continent, China and India (Mujica and Jacobsen, 2001). Other minor collections may be found in the United States and Argentina. Most collections include seeds of species grown at the expense of wild relatives, leaving important gaps in current collections.

Cytogenetic studies conducted in varieties of cultivated species show that all species are diploid and have a variable number of chromosomes. The number for *A. hypochondriacus* and *A. caudatus* is 2n = 32; the number for *A. cruentus* is 2n = 34 (Bonasora *et al.*, 2013).

Grain amaranth is an annual herbaceous plant, which can grow to significant heights (Figure 1.3a). The leaves are elliptic to lanceolate-ovate, with acute or acuminate apex. The inflorescence consists of large branches of solid green, red, yellow or variable colours, bearing flowers with or without pointed bracts. Stems tend to be more upright or pendulous, depending on the species. Likewise, seeds are extremely variable in colour. Amaranth seeds are able to germinate a few hours after being sown on moist soil. The radicle is the first structure to emerge, giving rise to a vigorous warped root, densely branched and with numerous small roots, which rapidly develops when branches start to grow from the stem.

Stems are cylindrical and angular, with thick, longitudinal striae, which give a channelled appearance. Stem diameter decreases from the base to apex. It reaches a height of 3 to 4 m. They may differ in colouration, which is usually similar to that of the leaves, although sometimes they show striae of different colours. On several occasions, branches originate from the base or from medium height, from each leaf axil. Leaves are petiiolate, and have no stipules. They exhibit an ovate, elliptic outline with entire margin and may be opposite or alternate. Prominent veins are seen on the reverse. They are smooth or a bit pubescent, green or purple. Size decreases from the base to apex and they are of variable height: from 6.5 to 15 cm (Itúrbide and Gispert, 1992; Mujica, 1992).

Inflorescence. The colourful panicles are amaranthiform (Figure 1.3b), terminal or axillary. They may be fully erect or decumbent. They bloom in colours including yellow, orange, coffee, red, pink or even purple. They reach a height of 0.5 to 0.9 m and take different shapes (Itúrbide and Gispert, 1992; Mujica, 1992). Flowers are unisexual, small, staminate and pistillate. Glomerules consist of dichasial cymes, which bear a terminal male flower that always opens first. Consecutive pairs of lateral branches of female flowers are inserted on the base of male flowers (Hunziker, 1952). Each glomerule may contain 250 female flowers. The percentage of allogamy ranges between 10% and 50%, even within individuals of the same population. Crossing depends on the wind, the number of pollinating insects and pollen production.

The fruit is unilocular, contained in a pyxidium that opens transversely at maturity. The operculum abscises and falls and the seeds inside the urn are exposed (Hunziker, 1952).

The seeds are small (from 1 to 1.5 mm in diameter) and shiny, slightly flattened, generally white, although sometimes yellowish, golden, red, pink, purple and black; and there are 1000 to 3000 seeds per gram (Figure 1.3c).

The grains contain the episperm, consisting of a very thin layer of cellular tissue; the endosperm; the embryo, made up of protein-rich cotyledon; and the perispern, rich in starch (Irving *et al.*, 1981). In general, seed dormancy has not been observed. Seeds may even germinate where water is scarce.

1.2.4 Cultivation

1.2.4.1 Growth and Development

Amaranth phenological characteristics vary extensively according to the cultivated species and the agroclimatic conditions where they are raised. However, generally speaking, sowing date up to 50% of flowering time may vary between 60 and 98 days

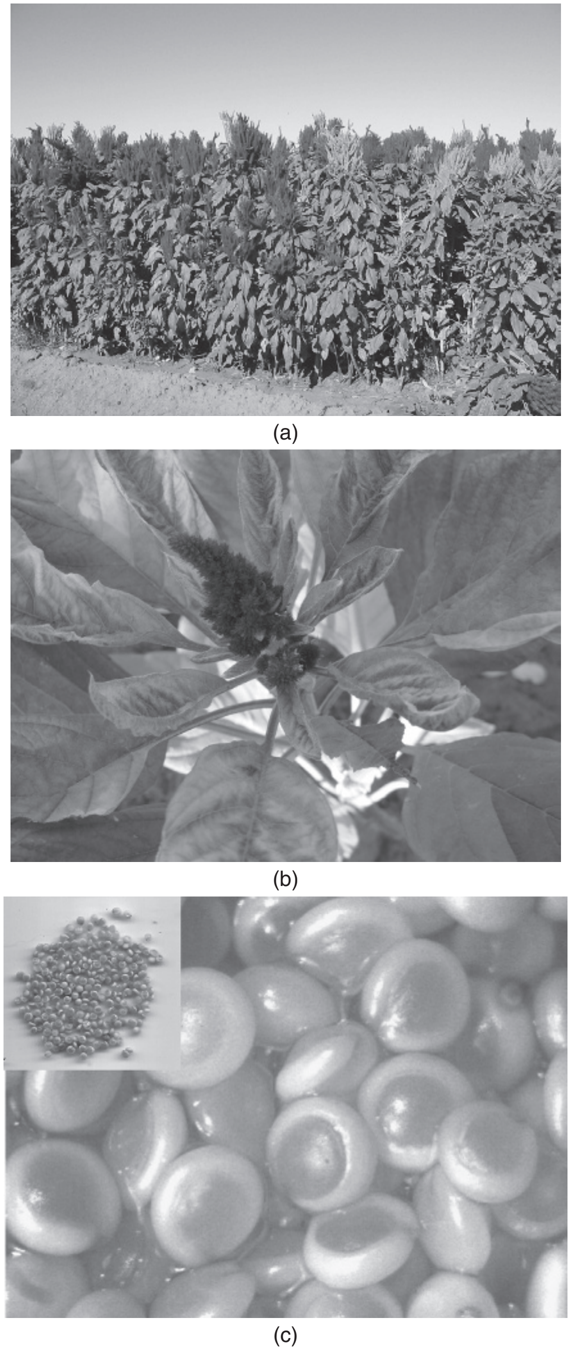

Figure 1.3 (a) Cultivation of amaranth; (b) inflorescence of amaranth; (c) amaranthus seeds. (*See color plate section for the color representation of this figure.*)

and, up to maturity, between 130 and 180 days. A description of amaranth phenological stages has been introduced by Mujica and Quillahuamán (1989) and Henderson (1993). Both sources coincide with the phenological stages described as follows:

1) *Emergence (VE).* In this stage, seedlings emerge from the soil, showing their two extended cotyledons. In the furrows, at least 50% of the population going through this stage is observed. All true leaves on the cotyledons are smaller than 2 cm in length. This stage may last from 8 to 21 days, depending on agroclimatic conditions.
2) *Vegetative period (V1Vn).* This stage is determined by counting the number of nodes on the primary stem. Leaves at the nodes may grow at least 2 cm long. The first node matches stage V1; the second one agrees with V2, and so on. As basal leaves senesce, the scar on the primary stem is taken into account in order to determine the corresponding node. The plant starts to branch in stage V4.
3) *Reproductive stage.* The beginning of panicle emergence (R1): the inflorescence apex may be noticed at the stem tip. This stage is observed 50 and 70 days after sowing. The panicle (R2) is at least 2 cm long. The end of panicle emergence (R3): the panicle is at least 5 cm long. If anthesis has already started once this stage has been reached, the plant should be classified as part of the following stage (R4) – here at least one flower is open, showing its separated stamens and the completely visible stigma. Hermaphrodite flowers are the first ones to bloom. Anthesis generally arises from the panicle's central axis to its lateral branches. In this phase, the plant is highly sensitive to frosts and hydrological stress. This stage can be divided into several substages, according to the percentage of panicle central axis flowers that have completed the anthesis stage. For instance, if 20% of central axis flowers have finished their anthesis, the stage will be R4.2; and if the proportion of central axis flowers reaches 50%, the stage will be R4.5. Flowering should be examined at midday as flowers stay closed during early morning or late afternoon hours. During this stage, the plant begins to eliminate older lower leaves, which are also less photosynthetically efficient.
4) *Grain Filling (R5).* At least 95% of the panicle central axis has completed anthesis. According to Mujica and Quihuallamán (1989), this stage can be divided into two stages. The milky grain stage occurs when seeds are squeezed out by pressing them between the fingers, and a milky white fluid appears; the dough-grain stage occurs when the seeds are squeezed out by pressing them between fingers and a whitish doughy substance may be noticed.
5) *Physiological ripeness (R6).* A definite criterion to determine physiological maturity has not been established yet. However, the change in panicle colour serves as the most commonly used indicator. Green panicles change their colour to golden yellow, and red panicles change to reddish-brown. Besides, seeds are hard, and it is not possible to dig nails into them. In this stage, when the panicle is shaken, ripe seeds will fall out.
6) *Harvest maturity (R7).* Leaves senesce and fall and the plant looks dry and coffee coloured. It is expected that autumn frost strikes in order to reduce seed humidity.

1.2.4.2 Climatic Requirements

Amaranth genotypes cultivated in rural agroecosystems of Mexico's central and southern regions are native or creole varieties. However, there exist a small number of improved varieties of two species: *A. hypochondriacus* L., which is grown in places with mild weather at an altitude from 1500 to 2200 m.a.s.l., and *A. cruentus* L., raised in places with warm weather and at an altitude from 400 to 1500 m.a.s.l. (García-Pereyra *et al.*, 2004). In the case of *A. caudatus*, the crops grow from Ecuador to the northern region of Argentina, in mild areas and inter-Andean valleys, with an altitude ranging from sea level to 3100 m.a.s.l. It is known to be a short-day species, despite its geographic adaptability to diverse environmental conditions. Flowering may occur within day lengths varying from 12 to 16 h. Moisture levels range from 400 to 800 mm; nevertheless, good crops may be grown with 250 mm, although reasonable moisture is essential for germination and flowering. Once established, amaranth is drought tolerant. In subtropical climate zones, harvest may occur twice a year, especially when the plant is watered.

In mild climate zones, cultivated areas mostly depend on the beginning of the temporal season from May to June, receiving 500 to 800 mm of precipitation. Crops raised in areas receiving 1000 mm of annual rainfall have been found. *A. cruentus* L. is sensitive to frost. Branching may withstand temperatures up to 4 °C and resist highest temperatures ranging from 35 to 40 °C.

1.2.4.3 Soil and Crop Management

Amaranth grows best in loam and loamy-sandy soils, with high organic matter content and good drainage, even though it may adapt to different kinds of soils. However, it does not generally bear clay soils. The optimal soil pH is 6–7, despite crops suited to acid soils with 8.5 pH. It is tolerant towards aluminium toxicity (Mujica, 1992; Soto, 2010).

Amaranth is planted either by transplanting in fields called *chinampas* (in the central region of Mexico) or direct sowing. Transplanting is an ancient method still widespread in some areas. It consists of raising seedlings for later transplanting to the field. Direct sowing is more common in southern Mexico. It is carried out in the back (upper border) of the furrow, on streaming, at the beginning of rainy season. Then plants are pruned when they reach a height of 10 to 15 cm. Generally, cultural practices are similar to corn growing: earthing up, two-staged fertilization and weed control. Harvest in those crop areas is like that in the Mexico Valley. From September to October, panicles are cut and, once all the stem leaves are dried, they are all arranged in piles and they are beaten to separate the seeds. Northeastern Mexico *A. cruentus* and *A. hypochondriacus* genotype tests show variable yields reaching from 800 to 2300 kg/ha, although it is possible to increase these values by sowing a larger volume and by using fertilizers (García Pereyra *et al.*, 2009; Kaur *et al.*, 2010).

In the Andes of Peru, Bolivia, Ecuador and Argentina, *A. caudatus* is cultivated in a traditional way and sowed in unirrigated lands, without fertilizers. Other cropping systems such as direct sowing, irrigated or unirrigated transplanting, associated with corn, intercropping, trap cropping, horticultural sowing next to housing, smallholding and larger areas may be used. The seeds are very small, so soil preparation jobs such as breaking up of clods and shaking up are needed. For that reason, it is recommended to plough, then to harrow and make the furrows either in a traditional manner by using a yoke or mechanically. Sowing is often associated with corn and, in the case of a single crop, is done in furrows separated by a distance of 80 cm, on continuous streaming. When the plant is 20 to 25 cm high, the first weed control is implemented. Then thinning follows when seedlings are crowded or should be transplanted to soils with higher moisture levels (Mujica, 1992).

Weed control is conducted manually. In some cases (when harvest time is close), roguing – that is identifying and removing plants with undesirable characteristics – is recommended. Earthing up should be done immediately after weed control is carried out because it improves crop stability when the plant is more than 1.5 m high. Amaranth crops generally grow in dry lands. However, in irrigated lands soil should be prepared by heavily irrigating the land. Then soil should be moderately irrigated when sowing and at the beginning of flowering, and lightly irrigated during the vegetation development. In this stage, the amount and frequency of irrigation vary according to soil characteristics and weather conditions. In case of shortage of rain, irrigation will be necessary every 30 days and especially at the flowering and grain filling stages (Rojas *et al.*, 2010).

Harvest is done before full maturity to avoid grain shedding. It consists of cutting the plants 50 cm above soil with sickles. They are gathered as small sheaves on furrows until they dry. Then they are hit with sticks while they are laid on extended clothing or tamp soil for threshing and sifted to separate seeds from dead leaves. Crop improvement consists of adequate soil preparation and direct sowing with a density of 4 to 6 kg/ha of selected seeds, in 80 cm furrows, using fertilizers according to the amount of soil nutrients. Cultural work consists of weeding once or twice and a quick earthing up to avoid falling over caused by inflorescence weight (Soto, 2010).

Yield varies from 2000 to 5000 kg/ha in Peru and 900 to 4000 kg/ha in Ecuador.

1.2.4.4 Diseases

Pythium spp. and *Fusarium* spp. are the most frequent diseases that affect seeds. Fungal diseases such as *Sclerotinia* spp. and *Alternaria* spp. cause stem and root rot. The most common pest is *Diabrotica* spp., known as *loritos*, which may harm the plant during emergence. Other pests are *Agrotis* spp. and *Eupicata* spp. In crops in Buenos Aires, the attack of the blister beetle (*Epicauta adspersa*) and the red weed caterpillar (*Loxostege bifidalis*) was noticed. They caused severe defoliation in upper leaves. These pests were controlled by using 1.5% of diatomaceous earth. Under the same growing conditions, panicle damage caused by isolated individuals of spotted maize beetle (*Astylus atromaculatus*) was also detected. It was controlled by spraying with chlorpyrifos (600 cm^3) and pyrethrins (150 cm^3) (Jacquelin *et al.*, 2011).

1.2.5 World Production of Amaranth

In the business environment, amaranth has no specific harmonized tariff but it is included in the 'other cereals' (1008.90.10 and 1008.90.90, 11 digits) and 'other cereal flours' (1102.90.00.900D) categories. Although there are no worldwide official sources that specifically show the volume of production of amaranth, the increase in 'other non-milled cereals' world exports (the category where amaranth is included) showed a general growing trend from 2007 to 2012, probably as a consequence of an increase in the production volume. The two main exporting countries were Peru and Bolivia, with exported values per ton ranging from USD 360 (the lowest in 2009) and USD 640 (the highest in 2011). Within the same period, Germany, France, Lithuania, Poland and China were the most relevant countries as to business transaction volume (Ministerio de Agroindustria, 2013).

1.3 Buckwheat – *Fagopyrum esculentum* Moench

1.3.1 Introduction

Fagopyrum esculentum Moench, known as 'buckwheat', is cultivated in Russia, Hungary, Poland, the Czech Republic, Denmark, France and Germany. In America, the producing countries are the United States of America, Canada and Brazil. The development of this species is considered not only as an agricultural activity that protects the environment but also as a significant food resource due to its nutritional benefits.

1.3.2 Origin and History

Native to the steppes of Central Asia and Siberia, the first crops were raised in the southern region. Then known as 'buckwheat', this species spread to the West along trade routes and due to invasions. The first records date back to the ninth and tenth centuries in China. Later, buckwheat was introduced to Turkey, Poland through Russia, and then was brought to France, Italy, Switzerland and Austria. The expansion of the crop originated from the seventeenth and eighteenth centuries, reaching Great Britain, the United States of America and Canada.

Buckwheat has been grown in the northeast and central north United States since colonial times, reaching its peak in 1866 due to demand for the seed to make flour and use of the fruit as animal breeding food. As a consequence of immigration flows, it was taken to Chile and Brazil. Ukrainian and Polish immigrants came to America in 1897 and settled down in the province of Misiones, Argentina, and they grew this species for their own consumption. According to Ukrainian tradition, milk, honey and buckwheat cannot be absent from the New Year's meal, as it is a good omen.

Buckwheat is a short season crop, the fruits ripening in the course of 3 months. It has a remarkable adaptability to different kinds of soils, including poor soils with low fertility. For that reason, it was cultivated in the sixteenth century by low-income European people.

It is thought that this plant was brought to North America by Dutch immigrants, who called it *wheat of writings*. In Europe, as well as in Asian countries, buckwheat has been a staple food since ancient times as it is a source of high biological value protein of vegetable origin. It is used for making flour due to its starch content. As it contains no gluten, buckwheat can also be eaten by people with coeliac disease. Between 2% and 3% of rutin (*quercetin-3-O-rutinoside*) is obtained from its leaves, reaching 5% to 8% of this component in improved varieties. In order to extract it, the harvest is gathered when the plant is still green (Oplinger *et al.*, 1989). This active ingredient is used for patients who suffer from venous and lymphatic insufficiency, for symptomatic treatment of hair fragility disturbances, haemorrhoids and for visual acuity and visual field disorders of vascular origin (Bruneton, 2001).

1.3.3 Botanical Characteristics / Species / Varieties

Hlásná Cvepková *et al.* (2009) cites 77 accessions. In *Fagopyrum esculentum* Moench, Oplinger *et al.* (1989) express the view that the majority of cultivated buckwheat accessions in the United States are diploids.

Buckwheat is an annual short-season herbaceous plant with many branches. It grows 60 to 70 cm high and has a primary root and an erect smooth stem. Its leaves are simple (Figure 1.4a), entire, and sagittate (arrow shaped). Lower leaves are petiolate, and the upper leaves are sessile, with a length ranging from 5 to 10 cm. They present a smooth edge, a cuspidate apex, palmate venation, developed leaf axil called *ocrea*, alternate phyllotaxis. Its flowers are pink or white and the hermaphrodite is small (Figure 1.4b). They present actinomorphic symmetry, calyx of five sepals, corolla of five petals, androecium of nine stamens of two whorls: one of six stamens and the other one of three, with shorter filaments; upper gamocarpelar gynoecium, with three carpels, capitate stigmas, hardly fimbriate, trigonous unilocular and uniovulate ovary; orthotropic ovule and basal placentation. Flowers are arranged in corymbose paniculate clusters (Figure 1.4c).

Reproduction occurs by means of crosspollination, presenting heterostyly, different-length stamens and styles. The fruit is a triquetrous achene (Figure 1.4d), with a wooden pericarp and one triangular lenticular seed that ripens irregularly, occurring in the perisperm, the embryo being antitropal peripheral, axial and curved. It has a mealy endosperm (Parodi, 1972).

1.3.4 Pseudocereal Culture

1.3.4.1 Growth and Development

Buckwheat's early crops complete the cycle from sowing to seed ripening within 80 to 90 days. Crops with longer cycles will do it within 100 to 110 days. Once the sowing has been done, the emergence of cotyledons can be observed on the second or third day (Figure 1.4e).

This stage lasts from 6 to 10 days, depending on weather conditions. After emergence, the vegetation period takes place: the epicotyl starts to develop, the first leaves begin to appear and the growth in length occurs in the place where the leaves are inserted, giving rise to internodes (Figure 1.4f). On the stem, leaves are formed at the nodes and the branching begins its development (Figure 1.4g). The reproductive stage occurs 20 or 30 days after sowing, when the paniculate corymbose clusters (Figure 1.4h) start to develop. This stage takes 2 months. Meanwhile, lower leaves abscise and fall. In this stage, the plant is sensitive to hydrological stress and frosts. During physiological maturity, the ovary becomes the fruit and the seminal rudiment turns into the seed. This stage takes 60 to 70 days; the growth is indeterminate. At the same time, the plant has both flowers and immature green fruits and mature fruits. Fruits reach harvest maturity within 75 to 80 days. In this stage, lower leaves abscise and fall and the fruit changes its colour from green to dark brown.

1.3.4.2 Climatic Requirements

For the plant to reach physiological maturity, the sowing season should be determined considering that buckwheat thrives in cool, moist climates and that it is not frost tolerant. During flowering and seed formation, plant development is affected by unfavourable weather conditions, dry climate and high temperatures. In Cantabria, Spain, experimental trials have been conducted in unirrigated soils located in different climatic conditions and at various altitudes such as: (i) the coastal area of Cóbreces at 80 m.a.s.l., (ii) Soba at 574 m.a.s.l., (iii) Valderredible at 730 m.a.s.l. and (iv) Celada at 925 m.a.s.l. Better agronomic behaviour was observed in the coastal area of Cóbreces, characterized by its lower altitude, cool climate and moderate temperatures (García Méndez *et al.*, 2014). Rainfall characteristics and frequency must be considered in order to attain good plant development and flowering, thus achieving a good yield from unirrigated crops.

1.3.4.3 Soil and Crop Management

Buckwheat can be grown in a wide range of soil types with different fertility levels. Better yields are produced from fertile, well drained soils (Tkachuk *et al.*, 1996). It is a very coarse species that tolerates acid soils. Buckwheat tolerates acid better than other species producing grain; it is effective in extracting phosphorous from low-phosphorous soils. This species does not thrive either in soils with tosca layers near the surface or with high limestone content or in wet, heavy soils. The coating formed on clay soils makes the plant's emergence difficult (Oplinger, 1989). Well drained medium-textured loam, sandy loam and silt loam soils are best suited to grow this crop. The cultivable soil layer must be deep and it must not be flattened because this is not a flood-tolerant species. Before starting with the preparatory work, the plot should be checked in its longitudinal section for impermeable soil layers that could hinder drainage. The necessary corrections should be made when surplus surface water does not percolate rapidly. When tilling takes place, the destruction of soil structure by excessive clearing of arable profile should be avoided. The formation of compacted soil layers in depth strata should also be prevented. Tilling should take soil texture into account. In irrigated crops, plots should be levelled for an even water distribution. Levelling blades are used to achieve the necessary slope (Figure 1.4i). In dry climate soils, the organic matter represents less than 5% of the solid phase.

Compost should be added to reach an adequate fertility level and to improve the soil texture and structure as well. Organic matter allows the addition of particles, which in turn form more porous structures. It also increases the capacity of cationic exchange as well as of water retention in soils. Organic matter in the form of compost can be added either manually or mechanically. In case the crop is rotated with vegetable crops to which manure was added, the nutrients then provided will be available during the buckwheat crop development.

The plot is prepared by tilling the soil with a mouldboard plough or a disc plough. This work is done when residues of the previous crop, green manure and weeds are still in the plot, in order not to affect the seeder machine work. Early tilling allows the nutrients available from the previous crops to be stored in the soil. It also improves the soil's physical condition. The crop residues must have no influence during sowing; burning them is not advisable. If prior to buckwheat some other cereal has been grown in the plot, weed tilling should be carefully performed so as to avoid the formation of a surface layer of straw that could hamper sowing and buckwheat emergence (Napoli *et al.*, 1994). In extensive unirrigated crops located in the northern hemisphere, buckwheat is used for rotation in temporary grasslands, the soil being prepared in April. In the southern hemisphere, tilling is done in June, after the harvest of the grasslands or crops. Seeds of the weeds remain 2 cm deep of the soil superior layer and germinate after rain. When weeds emerge, a disc harrow is drawn (Figure 1.4j), dispersing all the green material. Then a second ploughing is done and the plot is ready for sowing.

Fertilization. The need for nutrients is calculated according to the soil characteristics, the availability of the elements found in the soil and the irrigation system. The next crop is also considered because it will extract nutrients from the soil. The use of manure and / or fertilizers requires a prior soil analysis to add the necessary nutrients. Adding high nitrogen levels results in a great vegetative development that, in turn, causes lodging of the plant and its greater susceptibility to cryptogrammic diseases.

Napoli *et al.* (1994) state that for every 1600 kg of seed produced per hectare, the crop extracts from the soil 47 kg of nitrogen, 22 kg of phosphorous and 40 kg of potassium. Phosphorous is needed for growth and production of flowers. If it is not found in the soil in sufficient quantities, it is added as diammonium phosphate at the moment of sowing acid soils. At a higher pH, monoammonium phosphate is preferable.

Direct sowing. Rows are spaced apart about 15–17 cm; sowing depth is of 4 cm; a fine grain drill is used and seeds should remain in contact with the wet soil. Each hectare takes 60 to 70 kg of seeds. If less is used, the plants will branch out and there will be a significant vegetative development, which will in turn cause lodging of the plant (Napoli *et al.*, 1994). If the soil has been tilled previously, pneumatic precision seeders for vegetables could be used, thus consuming less seeds. To protect the soil structure, tilling should not refine the land in excess. Seeds germinate at temperatures ranging from 20 to 25 °C. In each geographical site, the appropriate sowing date should be considered for the vegetative and the reproductive cycles not to be affected by frost. In Aragón, Spain, located in the northern hemisphere, it is advised that sowing is done during June / July –according to trials carried out in Valderredible by García Méndez (2014). In this area, a higher yield was observed in the plots that had been sown during the summer, with a

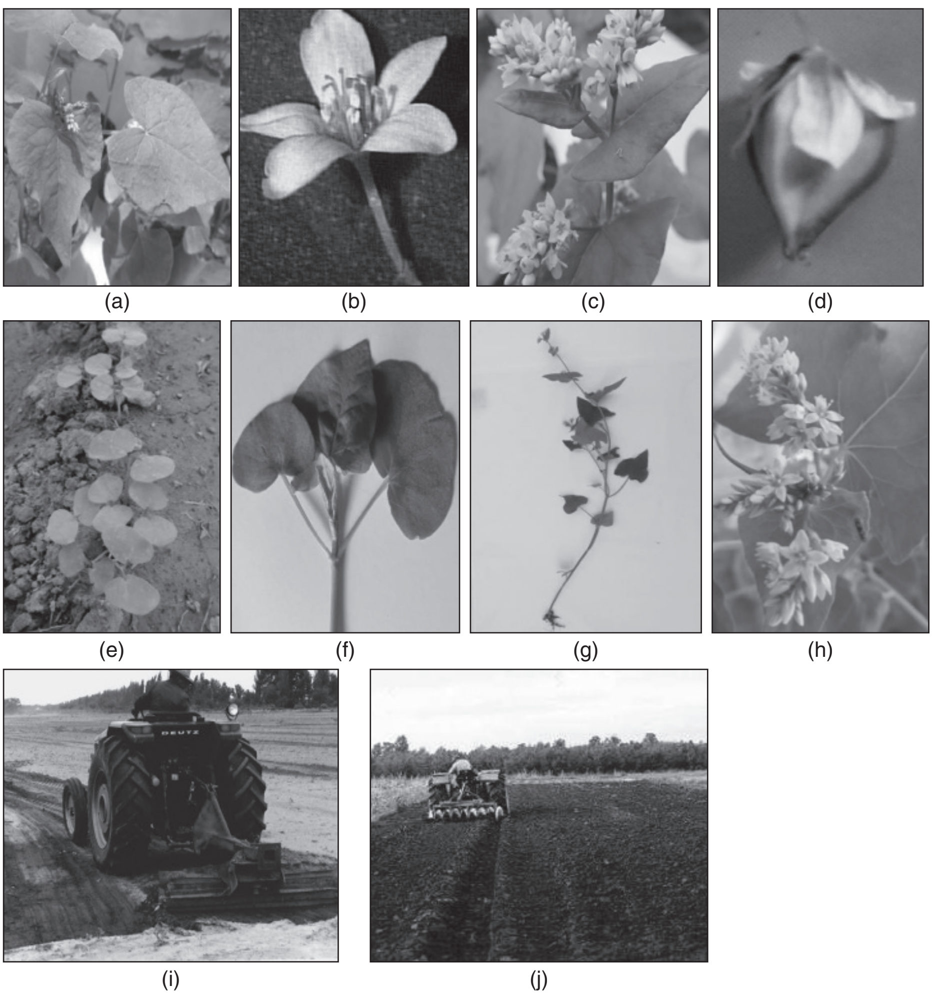

Figure 1.4 Buckwheat: (a) simple leaves; (b) hermaphrodite flower; (c) inflorescence; (d) fruit achene; (e) emergence; (f) first leaves; (g) branches begin; (h) corymbose; (i) levelling; (j) soil preparation; (k) crop uniformity; (l) forms the fruits; (m) seed is mature; (n) harvest; (o) clean fruit. (*See color plate section for the color representation of this figure.*)

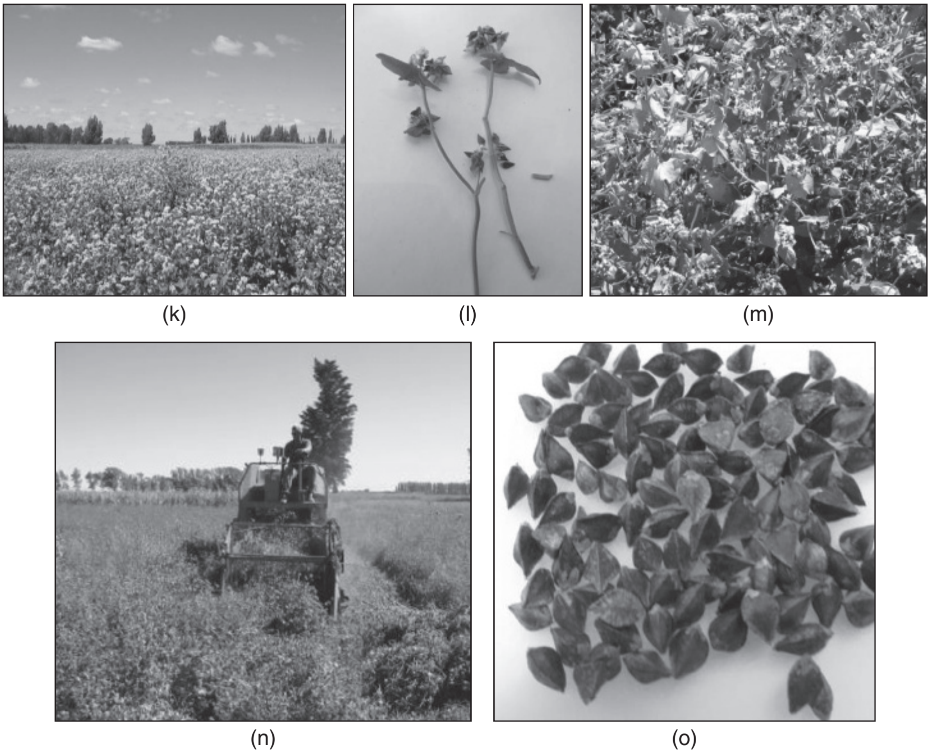

Figure 1.4 (Continued)

production of 1400 kg/ha. In the southern hemisphere, the trials carried out by Dionisi (2012) in the province of Córdoba and by Napoli *et al.* (1994) in the province of Misiones, Argentina, proved that sowing must be done after all risk of frosts is over.

Irrigation and cultural labour. In irrigated crops plots, if there is pumping equipment at the exploitation site, the plants are watered during their emergence. After sowing, no cultural work is done given the closeness of the cultivated rows and the fast vegetative growth of the plant, conditions under which weeds find no appropriate growth environment. In a short time, the crop reaches a high plant density and the plants compete with the weeds (Napoli *et al.*, 1994). Figure 1.4k shows the crop uniformity and the density reached in a buckwheat plot. Figure 1.4l shows the fruit.

Harvest – yield. Harvest takes place when 75% of the seed is mature (Figure 1.4m). From the sowing to the harvest, 75 to 80 days go by for short-cycle varieties, and 120 days for long-cycle varieties. Harvesting is done in the morning when the crop is wet with dew, thus decreasing shattering losses. To reach all flowering levels, plants are cut in their lower stem. The harvest equipment cuts and puts the cut plants into rows (Figure 1.4n).

Vegetal biomass is left in the field to dehydrate and when it reaches a humidity of 14–16%, it is threshed. Then, it is cleaned using sieves to remove dirt and vegetable waste. In the storage section, the clean fruit (Figure 1.4o) is stored at 14% moisture in bags that are placed on pallets raised 15 cm above the ground. The environment must be kept clean and pest control for weevil, woodworm and rodents must be carried out. The yield is highly variable and it fluctuates between 600 and 2500 kg/ha.

1.3.4.4 Diseases and Pests

The research carried out in Cantabria, Spain, by Garcia Menendez (2014) revealed the existence of neither diseases nor pests. In the trial conducted in Córdoba, Argentina, by Dionisi (2012), the infections detected had no major impact on production. In crop trials carried out in Cerro Azul, Misiones, Argentina, Napoli *et al.* (1994) observed the following diseases, which occasionally affected the crops in northeast Argentina:

- *Rhizoctonia* sp., a basidiomycete fungus that develops in winter time. It attacks primarily the roots, neck and hypocotyls of plants and leaves in contact with wet soil. In adult plants, it causes damping off, root rot and stem canker. Blight is observed in the lower leaves near the soil. Plants die soon after emerging, mainly in wet soils. Control is conducted with antagonistic fungi *Trichoderma harzianum* (Agrios, 1996).
- *Ramularia* sp., a fungus that forms conidia. It develops in humid environments at 20 °C and does not thrive in temperatures above 27 °C. The leaves show white spots that turn to light brown. A late infection does not affect the yield; early attacks cause defoliation and production losses due to photosynthetic activity reduction. The infection and its development are observed under constant rainfall conditions.
- Aster yellow is a mycoplasma-like organism that leads to bast necrosis with growth interruption. If the plant survives the infection, the flowers show an abnormal ramification phenomenon and calyx hypertrophy; the petals turn greenish or stunt growth; the stamens become sterile and the carpels gain foliaceous structure. It is passed on by vectors: major epidemics are related to the presence of wild plants as reservoirs and to the proliferation of cicadellidae vectors. Control involves eliminating reservoir plants and increasing parasitoids, such as hymenoptera from the *dryinidae* and *mymaridae* families.
- *Pests*. It has been observed that, before the harvest takes place, crops – especially lodging plants – can be attacked by ants, aphids and worms. They can also be damaged by birds and rodents. Control must be enhanced by increasing the activity of natural enemies of the pests that affect the crops, among which there are other insects, fungi, bacteria and pathogenic viruses (Lampkin, 2001).
- *Ants*. Major damage could be caused mostly in times of drought because buckwheat is the only crop that continues growing. Preventive control of ants' nests should be done in the plot to be cultivated and in the outlying strips.
- *Aphids*. Biological pest control is advised, favouring the development of grub and adult coccinellidae, microhymenopterae, carabidae and grub chrysopidae, syrphidae and mantidae nymphs, all of which are voracious natural enemies that attack aphids, butterfly eggs and lepidopter caterpillars.

1.3.5 World Production of Buckwheat

According to a study conducted by Fantasía (2009), the world's buckwheat production reached 3 000 000 tons with annual fluctuations. Buckwheat-producing countries are also the largest consumers: China produces 55% of the world's total production; Russia, 20%; Ukraine, 15%, and Poland, 3%. American producing countries such as the United States of America, Canada and Brazil are exporters.

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