Pseudocereals
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Chemistry and Technology

Edited by

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Preface

Pseudocereals are a group of nongrasses, the seeds of which can be ground into flour and then used like cereals. The main pseudocereals are amaranth (Amaranthus spp.), quinoa (Chenopodium quinoa) and buckwheat (Fagopyrum esculentum and Fagopyrum tartaricum).

Compared to the true cereals, pseudocereals are still underutilized and cultivation is low but, in recent years, worldwide demand for them has increased immensely, resulting in an increase in their production but also an increase in their price. For many years pseudocereals have been widely recognized for their nutritional value by food scientists and food producers. They contain high-quality proteins, abundant amounts of starch with unique characteristics, large quantities of micronutrients like minerals, vitamins and bioactive compounds and they are gluten free, which makes them suitable for people suffering from various gluten intolerances. For these reasons, interest in pseudocereals has increased immensely since the turn of the century and research efforts have been intensified.

This book summarizes the large amount of recent research on pseudocereals and provides comprehensive and up-to-date knowledge within all the relevant fields of food science. It provides information on the origin of pseudocereals, their botanical characteristics, production and utilization, structure and chemical composition, paying special attention to carbohydrates, fibres, bioactive compounds, proteins and lipids of kernels. It includes dry and wet milling, various food products and applications, as well as gluten-free products. The nutritional and health implications of pseudocereals are also addressed.

We hope that this book will contribute to an increased use of pseudocereals in human nutrition by consumers worldwide.

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1

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 agroecological 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-Diaquie 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.

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 Hóega 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 hircinum 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 Canahuia, 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.
  - 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 phylotaxis.
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 phylotaxis. 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 presents 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 Qhullirí (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 tillling 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.

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

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