# chapter three

# Pseudocereals (without millets)

## 3.1 Buckwheat

### 3.1.1 Introduction

Common buckwheat (*Fagopyrum esculentum* Moench, syn. *F. sagitatum* Gilib., *F. vulgare* T. Nees, Hill) used to grow primarily in Asia (Pendzab, Tibet, and Poamur regions); today, however, wild plants can be found in China (Himalaya Mountains), Siberia, and the Far East. Chinese people planted buckwheat as early as the eleventh century BC, and the diploid genotype of buckwheat has been grown in Mongolia since the tenth century. Buckwheat was first mentioned in European countries in 1396, and it has been grown in the U.S. ever since the seventeenth century.

Three different explanations exist for the naming of buckwheat. The origins of the English word "buckwheat," the Netherlands term "boekweit," and the German term "Buchweizen" can be traced to the Greek name "Phagos" for beech combined with the word wheat, because the seed of buckwheat is similar to the tetrahedron form of beech seed. The second explanation originates from the terms "Heidenkorn" (German) and "Pohanka" (Polish), which translate to the cereal of fallows and the buckwheat produced by paynims. The third and final explanation is that the Spanish term "al-forfon vs. al-furfur" describes the dark red or purple color of the buckwheat plants [1]. In China, buckwheat is also called "black wheat," "flowering wheat," and "triangle wheat" [2].

Buckwheat is a cosmopolitan pseudocereal with limited production compared to cereals with higher yields. However, it is currently being introduced in many more countries, due to the high nutritional value of the buckwheat seed. The seeds are rich in essential amino acids, fatty acids, minerals, and vitamins $B_1$ and $B_2$. Buckwheat is also an important human dietary source. It is also used in honey production (possible yield is 120 to 300 kg of honey $ha^{-1}$); soon after the initial stages of flowering, two beehives $ha^{-1}$ can be placed. Every day, bees can collect up to 5 kg of honey from each beehive.

Buckwheat has a darker color and stronger taste than other kinds of flower honey, and it works as an antioxidant and plasma reducer in healthy human adults, potentially protecting the body from oxidative stress [3]. After bee pasture or unsuccessful fertilization, buckwheat can be plowed under and used as organic fertilizer: produce of above ground mass, which can also be used as quality animal feed, can amount to 7000 kg of dry matter $ha^{-1}$.

Buckwheat has become a popular food source all over the world, especially in Japan, the U.S., and some European countries, because of its use in traditional components of modern cuisine.

## 3.1.2 Botany

### 3.1.2.1 Taxonomy

This annual plant belongs to the *Polygonaceae* family and *Polygonum* genus. The *Polygonum* genus includes 15 species, three of which are known in common utilization: common buckwheat, known in in our case as simply buckwheat (*Fagopyrum esculentum* Moench, syn. *F. vulgare* Hill.); tartary buckwheat, sometimes called crazy buckwheat (*Fagopyrum tataricum* [L.] Gaertn., syn. *F. dentatum* Moench, *Polygonum tataricum* L.); and *Fagopyrum cymosum* Meins. Common buckwheat is divided into ssp. *vulgare* and ssp. *multiflorum* St., according to intensity of growth, number of leaves, and number of branches. *F. esculentum* ssp. *vulgare* includes var. *alata* Bat. and *aptera* Bat, according to characteristics of the seed var. *marginata* and *rhombea* [4].

### 3.1.2.2 Morphology

Cultivated and land race populations of buckwheat have various plant types. Certain standard differences exist between common and tartary buckwheat: tartary buckwheat has yellow-green flowers, wide and short leaves, and jagged margins of seed, while common buckwheat has petal flower leaves that are white or violet, without the characteristics of tartary buckwheat seeds. The depth of the main root varies between 0.6 and 1.2 m. Although roots are richly branched, the dry mass of root hair represents 3% of the full plant weight [4]. Root length increases constantly until peak flowering, reaching a length of 1.8 km $m^{-2}$ at harvest [5].

The stem often ranges from 0.3 to 1.0 m high, and can even reach 3.0 m, depending on genotype and growth conditions. The stem can either be branchless or branched with first order branches at the second, third, and fourth nodes.

In the upper inflorescence a growing point is hidden, which is active in suitable ecological conditions. High plant-population density can be used to prevent intensive side-branching. The leaves and stems of buckwheat are often red because of the presence of antocian.

A sphere appears over the upper-side branch, which begins to flower 4 to 6 weeks after sowing. Each flower cluster's blooming process lasts a relatively long time — about 20 days — and, consequently, ripening is not uniform (Figure 3.1). Forms displaying limited growth have been found

***Figure 3.1*** Ripeness of buckwheat.

within some buckwheat genotypes; these genotypes are known as determinate buckwheat, an example of which are the Slovenian cultivars Siva in Darina. Determinate plants are more resistant to lodging and form more branches in suitable growth conditions.

The buckwheat's leaves grow from nodes. They are of cordate shape, 5 to 10 cm long, and alternately placed. The buckwheat flower consists of five petals of single flower integument, eight stamina, and one pistil. The flower formula is P5A5 + 3G(3), or P5G(3). Flowers are joined in clusters, and sometimes spikes form. Flowers in individual populations are divided into two types: those with long pistil and short stamina (pin type) and those with long stamina and small pistil (thrum type). Both types of buckwheat flower exist within one variety. Flowers are predominantly heterosterile; cultivars with a higher percentage of self-pollination are selected. In principle, the pollination of pin flowers is possible only with pollen from plants of the thrum type, and, conversely, pollen from the pin type may successfully fertilize only flowers of the thrum type [3].

The buckwheat seed is a single-seeded fruit: acorn (achene), three-edged seed, 6 to 9 mm long, with a rounded form. The acorn consists of a dicotyledonous embryo surrounded by an endosperm, enclosed by a testa and pericarp (hull). The embryo is found in the center of the endosperm, and cotyledons appear in the shape of the letters "s". One buckwheat plant can grow anywhere between 10 and 200 seeds. The seeds can be dark brown nearly black in color, or they may appear silver-grey to light grey. Hulls (per carp) comprise 18 to 40% of the acorn joint mass, which is determined by husking 20 samples of 20 acorns. The normal mass of 1000 acorns falls between 18 and 32 g, though it may reach as high as 38 g in metalloid form. Hectoliter mass varies from 54 kg $hl^{-1}$ to over 62 kg $hl^{-1}$.

The chemical components in an acorn are the following: 10 to 13% water, 61.4 to 66.9% extractive substances without nitrogen, 1.9 to 3.2% fat, 9.7 to 19.9% raw cellulose, 1.6 to 2.9% ashes, and 11.0 to 15.4% proteins [4]. The main phenolic components consist of epicatechin, rutin, hyperoside, and quartecin. A simple, reliable, and reproducible method based on capillary electrophoresis with electrochemical detection for their analyses has been found [6].

### 3.1.3 *Production and yielding*

Russia, China, and in 16 other countries currently produce 90% of the world's buckwheat across 3 million hectares of land. Other important buckwheat producing countries are Ukraine, Poland, Brazil, the U.S., France, Japan, Kazakhstan, and Canada. Smaller, traditional producers also exist in Hungary, Slovenia, Croatia, and the Baltic countries Lithuania, Estonia, and Latvia. Although data about the exact percentage of organically produced buckwheat is lacking, but it is clear that the organic production is increasing worldwide.

Grain yields are variable. If buckwheat is grown during a summer that is too hot or too cold, or in unsuitable soil or without pollination by insects, the yield may be as low as 500 kg $ha^{-1}$. The approximate yield for buckwheat is between 800 and 1000 kg grain $ha^{-1}$, but in favorable conditions, it can reach 2200 kg grain yield $ha^{-1}$ [4]. In some cases, producers have been satisfied using buckwheat as the main crop in areas with vegetation periods that exceed 150 days. Buckwheat grown as a full-season crop has a higher leaf area index, more clusters, better developed seeds, and 42% higher yield than the stubble-crop buckwheat [7]. Due in part to recent findings, the interest in buckwheat and its production is increasing, especially with regard to certified organic production.

### 3.1.4 *Growth and ecology*

Buckwheat seeds were often used as food in undeveloped and marginal regions. Due to higher yields of other field crops, however, the use of buckwheat did not spread to wider areas. The cultivation of buckwheat as a main crop was abandoned, according to globalization trends, because the production of main crops like corn and wheat that grew in monoculture proved more profitable [8].

Buckwheat demands specific climatic conditions. Production is possible far north (68° of northern latitude); in the Himalayas, buckwheat can even be produced at 4000 meters. Growth is limited by June isotherm 17°C in the north and 20°C in the south. It is very sensitive to cold: the lethal temperature for buckwheat ranges from –1.3 to –2.9°C, depending on the growth stage and conditions [9]. The plants are highly sensitive to frost from the early stage of primary leaves to the development of two secondary leaves. Differences among growth stages develop with plant hardening during growth and the critical time of frost action. Buckwheat is also not resistant to heat accompanied by drought. If temperatures exceed 30°C at the flowering stage, fewer flowers will form, and pollination will either be less satisfactory or simply not occur. In addition to oversensitivity to cold and heat, buckwheat is also vulnerable to profuse rain and wind; both may interfere with successful pollination. The decrease in grain yield may be caused by flooding at the flowering and the ripening stages for more than 10 and 3 days [10].

In order to achieve a growth capacity between 50 and 90%, soil moisture and temperature of 8–10°C is needed, with a minimal temperature of 4–5°C. The optimal germination temperature is 26°C; germination period at this temperature is 3 days. The optimal temperature during flowering is between 19 and 25°C. Assimilation stops with temperatures lower than 10°C; if temperatures exceed 24°C, pollination ceases [4].

Ripening of buckwheat (75% of acorns ripen) firmly correlates with accumulated growing degree days (AGDD, $r^2 = 0.93$). AGGD are also helpful for predicting optimal harvest time [11].

The transpiration coefficient of buckwheat is between 500 and 600. Although the transpiration coefficient of buckwheat is extremely high, the minimum amount of water necessary for buckwheat to survive, from germination to flowering, is 70 mm; at least an additional 20 mm are needed to reach the end of the growing period. A 3-day water stress during the first week of flowering reduces the number of seeds by 50% without reduction in seed size, dry weight, or number of formed flowers. The effect of water-deficit stress continues after irrigation and is expressed as a reduction in fertility and newly formed flowers [12]. Short days also hindered buckwheat growth. Plants under moderate irradiance (160 μmol $m^{-2}$ $s^{-1}$) exhibit higher growth, net assimilation rate, and osmotic adjustments than plants maintained under low irradiance (80 mumol $m^{-2}$ $s^{-1}$) [13]. Flower inductions also depend on day length and the number of inductive cycles. The critical day length varies with the genotype and growth parameters. Accordingly, it is necessary to choose the most appropriate cultivar for the main sowing or stubble-crop because such cultivar needs 9 hours of darkness for flower induction. According to some findings, the day before the start of anthesis significantly influenced the main stem elongation flowering process thereafter; this suggests that day length is a more critical factor for the differentiation than the growth of the flower bud [14].

Buckwheat growth peaks between 11:00 a.m. and 12:00 midday and is at its slowest between 6:00 p.m. and 9:00 p.m. It is significant for buckwheat to grow new shoots and leaves after flowering and even during ripening (though the determinant species is an exception). Buckwheat requires the most water in the first month, although the size of the leaf area multiplies later. Soil that is not plowed well does not enable uniform sowing depth, which results in uneven emergence, plant population, growth, and development [4].

The number of unfertilized flowers, formed seeds, open flowers, flower clusters, and ripening are conditioned by mutual influences, cultivar properties, sowing date, and plant population [15]. Branching largely depends on the cultivar and, according to numerous mutual influences on growth conditions, it is considered an important phenotypic property. Intensive branching can be regulated by sowing density with determinant cultivars, an important factor for reaching crop height [16]. Ripe acorns appear with buckwheat 5 to 10% of the time; an even more serious problem is caused by ripe acorns falling off. Buckwheat may take up to two months after the appearance of the first ripe acorns to harvest [17].

## *3.1.5 Organic cultivation practice*

### *3.1.5.1 Crop rotation*

Buckwheat production as a monoculture is not possible: continuous planting would result in diminishing yields. Buckwheat should not be planted again on the same field for at least 3 years, and 5 years is optimal. A negative consequence of incorrect buckwheat crop rotation is the increased occurrence of necrosis and the appearance of some disease signs, especially root diseases caused by *Gaeumannomyces* sp. When crop rotation is not correctly applied, more polyphagous insects will appear and the quantity of weeds increases. Buckwheat can be grown as a main crop or stubble crop after previous crops such as wheat, barley, early potato, and more, depending on the duration of growth season. Buckwheat presents high yields when grown following pea crops and fodder plants sown in autumn and harvested in the middle of the spring. The potato and buckwheat share the same nematode; nevertheless, the crop rotation includes potato and buckwheat and is still recommended. Buckwheat sown as a main crop in appropriate areas reaches high yield after other legumes or arable crops [4].

Buckwheat contains 10 types of allelochemicals (e.g., gallic acid, H-catechin, and so forth) that inhibit the growth of some weeds. The buckwheat pellets' selective inhibitory effects become greater in early application in transplanted rice [8]. Buckwheat may have allelopathic potential; when used as a ground cover crop or green manure, it may produce inhibitors that could suppress weeds [19] and cultivate plants.

### *3.1.5.2 Soil, plowing, and presowing preparations*

Buckwheat can be produced in almost all types of soil, except in sand and wet or crusted soils. The optimal conditions are lighter, sandy-clay soils; products grown in extremely acid soil are of lower quality than those grown in neutral or lightly alkaline soil, but a high level of limestone in soil is also not suitable. Buckwheat should not be sown in soils rich in humus due to possible lodging.

Plowing stubble immediately is highly important to preserving moisture. After fertilizing, stubble should be plowed 12 to 15 cm deep. Fertilization can be undertaken immediately following plowing; in this case, quick presowing preparation is necessary to prevent any loss of moisture. Buckwheat must not be sown in dry soil [4].

### *3.1.5.3 Sowing and crop cultivation*

There are 4500 known genotypes worldwide (cultivars and land race populations), mostly suitable for only a single climatic area due to their extreme adjustments to photoperiodic reactions (day length included). Therefore, their introductions into new climates represent a significant risk to successful production. Bavec et al. [7] suggest that the best-yielding buckwheat genotypes should be determined and introduced separately for stubble-cropor full-season production systems.

Several different sowing systems exist worldwide. Sowing is suitable with interrow spacing of 7 to 8 cm with row spacing of 5 to 6 cm. We usually sow buckwheat with interrow spacing of 10 to 12 cm, depending on how the seeder unit is set for sowing cereals. It is sown for grain with longer interrow spacing if the available seeded requires it — the interrow spacing should thus be doubled (to 24 cm), with very high sowing density, which increases the possibility of lodging. Buckwheat used as stubble crop is sown after barley, early potatoes, or early maturing cereals if the growing season is long enough to allow the maturity of the buckwheat. The sowing date of buckwheat as main crop is limited by spring freezing; sometimes, the plants will not flower, depending on the photoperiod of the genotype. Seeds should have at least 75% germination.

The depth of sowing in sandy soil is 3–4 cm and, in heavier soil, 1–2 cm. We use 60 to 90 kg of seed (acorns) $ha^{-1}$ when sowing with 250 to 300 viable seeds $m^{-2}$ [4]. Sowing between 750 and 1200 seeds $m^{-2}$ gives a higher yield than sowing 100 to 300 viable seeds $m^{-2}$ [15, 17]. University of Maribor results [29] show the increase of yield after an increase in sowing density to 1250 viable seeds $m^{-2}$ (sometimes as high as 1500 viable seeds $m^{-2}$), although with lower yield profitability, higher seed expenditure is not justified. Sowing too densely results in thin and less-branched plants with low productivity per plant. However, based on genotype and branching under specific climatic conditions, the preferred plant population ranges from 170 to 200 plants $m^{-2}$.

The provision of pollination is very important for the buckwheat crop: two beehives per $ha^{-1}$ are needed. As discovered by the University of Maribor, and also by Goodman et al. [21], the activities of honeybees and other insects doubled seed production.

Wide interrow sowing used in some areas around the world results in the possibility of cultivation between rows. Mechanical weed control is used only with wide sowing, because plants do not cover the soil quickly enough. As a rule, weed control is not needed, because the plant develops rapidly and suppresses summer weeds very effectively on its own [22]. Sowing healthy and clean seeds without weeds is critical.

Pests do not cause economically significant damage; therefore, buckwheat can easily be produced organically. Polyphagous insect problems can usually be traced back to unsustainable agricultural practices. Degeneration and damage may be caused by peronospora, grey mold, and the fusarium, but buckwheat is usually free from diseases. However, the economic assessment of damage is low and unknown.

#### 3.1.5.4 Fertilization

In soil with low nutrient content, buckwheat grows better than other cereals. In humus soil with high nitrate content or potential mineralization, buckwheat often lodges. Buckwheat's demand for nutrients must be satisfied in order for it to be produced organically. According to our estimation, with production of 1500 kg of acorns per $ha^{-1}$ and 2500 kg of straw per $ha^{-1}$, the buckwheat crop uptakes about 45.5 kg of $P_2O_5$, 115 kg of $K_2O$, and 39 kg of CaO $ha^{-1}$. From this, grains take up 20 kg of $P_2O_5$, 15 kg of $K_2O$, 1.5 kg of CaO $ha^{-1}$, and about 27 kg of N $ha^{-1}$.

The required variation width of advised available nutrients differs in various production areas according to soil analysis, precipitation, and cultivars (from 44 to 88 kg N $ha^{-1}$ with lower production, to an unbelievable 234 kg N $ha^{-1}$ with production of 4000 kg acorns per $ha^{-1}$; from 26 to 132 kg $ha^{-1}$ $P_2O_5$ and from 33 to 165 kg $ha^{-1}$ $K_2O$). Sufficient boron content is necessary.

Nutrient uptake from organic fertilizers must be carefully considered and adjusted to meet the previously mentioned needs, with special attention paid to the precise uptake of nitrogen. If more than 20 g $NO_3$-N per $kg^{-1}$dry soil to the depth of 0.3 m exists during the sowing period, fertilization is not allowed. Mineralization will usually provide enough nitrogen, or the amount of nitrogen uptake does not exceed 40 to 60 kg N $ha^{-1}$. We do not use stable manure with stubble crop due to possible lodging problems; it should instead be used for the previous crop in the crop rotation. For basic or additional fertilization, compost is also suitable.

The efficient uptake of phosphorus from forms that present difficulty for other crops is a characteristic of buckwheat [4]. For example, it is highly efficient in taking up Ca-bound phosphorus compared to spring wheat, where the principal mechanism of phosphorus-uptake efficiency may be its ability to acidify the rhizosphere [23].

### 3.1.6 Harvesting, handling, and storage

Buckwheat is harvested when about 75% of the seeds have reached ripeness. Fully mature seeds are grey, brown, or black (depending on genotype characteristics) and fall off the plant during the vegetation period. The overall production period — from sowing to harvesting — should last 10 to 12 weeks under optimal climatic conditions. When buckwheat is sown as a full-season crop and the growing period exceeds 12 weeks, the decision about harvesting time depends on the number of fully mature seeds and the consequential grain yield. Humid and green masses cause difficulties at harvesting. The speed of the harvester and the rotation of the threshing cylinder have to be harmonized (600 rev. $min^{-1}$). High water content in plant stalks and seeds is typical at harvest (about 20-25%), whereas threshing during the dry summertime presents an exception. The grain should be dried to obtain 12% moisture (14% maximum) in the seeds for storage; otherwise, the seeds become stuffy and infected by mildews [4]. Edwardson [24] finds that it is safe to store buckwheat at 14 to 16% moisture.

Buckwheat may be stored under the same conditions as other grains. Due to the content of several natural antioxidants (tocopherols, flavanoids, and phenolic acids), buckwheat can be stored for long periods without any symptoms of chemical changes — only the occasional rancidity of grains or flour may occur.

## *3.1.7 Nutritional and health value*

### *3.1.7.1 Nutritional value*

Buckwheat seed contains between 11 and 15% high-quality and easily digestible proteins, which represent more than 90% of the protein value in skimmed milk and more than 80% of the protein value in dry eggs. Most represented proteins are globulins (approximately 40%), whereas prolamin content is low. Buckwheat grain contains 1.5 to 3.7% of lipids. Oils contain 16 to 20% of saturated fatty acids, 30 to 40% of oleic acids, and 31 to 41% of linoleic acid [25].

The nutritional value of buckwheat seeds and the products of milled seeds depend on the relative abundance of the various seed tissues in each (Table 3.1).

***Table 3.1*** Protein, Carbohydrate, Oil, Fiber, and Ash Content of Buckwheat Milling Fractions Compared with Other Products (% in dry matter)

| Product | Protein | Carbohydrates | Fat | Fiber | Ash |
|---|---|---|---|---|---|
| Seed | 12.3[a] | 73.3[a] | 2.3[a] | 10.9[a] | 2.1[a] |
| Whole groats | 12[c] | 57[c] | 4[c] | 7[c] | 2[c] |
| Bran | 36[c] | 24[c] | 11[c] | 15[c] | |
| Groats | 16.8[a] | 67.8[a] | 3.2[a] | 0.6[a] | 2.2[a] |
| Dark flour | 14.1[a] | 68.6[a] | 3.5[a] | 8.3[a] | 1.8[a] |
| Average flour | 11.7[a] | 72.0[a] | 2.5[a] | 1.6[a] | 1.8[a] |
| | 11.6[b] | | 2.3[b] | | 1.8[a] |
| White flour | 6.4[a] | 79.5[a] | 1.2[a] | 0.5[a] | 0.9[a] |
| Wheat flour | 11.8[a] | 74.7[a] | 1.1[a] | 0.3[a] | 0.4[a] |

[a] [26].

[b] Adapted data from [27].

[c] [28].

*Source:* Robinson, R.G., The Buckwheat Crop in Minnesota, *Agr. Exp. Sta. Bul.*, Univ. Minnesota, St. Paul., 539 pp. With permission from University of Minessota Extension Service, published in 1980.

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***Table 3.2*** Essential Amino Acid Composition of Buckwheat, Wheat, and Corn

| Amino Acid | Buckwheat | Corn | Wheat |
|---|---|---|---|
| Isoleucine | 3.57–3.69[a], 0.46[b] | 0.33[b] | 4.42[a], 0.46[b] |
| Leucine | 5.95–6.29[a], 0.84[b] | 1.20[b] | 8.24[a], 0.91[b] |
| Methionine | 0.97–1.14[a], 0.19[b] | 0.18[b] | 1.02[a], 0.18[b] |
| Phenylalanine | 4.11–4.54[a], 0.56[b] | 0.47[b] | 5.17[a], 0.64[b] |
| Threonine | 3.32–3.61[a], 0.49[b] | 0.33[b] | 3.12[a], 0.40[b] |
| Valine | 5.31–5.43[a], 0.60[b] | 0.44[b] | 5.12[a], 0.56[b] |
| Lysine | 5.38–5.76[a] | – | 3.26[a] |

[a] [27] (in mg $g^{-1}$ dry matter).

[b] [29] (%).

*Source*: From Belton, P. and Taylor, J., *Pseudocereals and Less Common Cereals: Grain Properties and Potential*, 2002. Copyright 2005, with permission of Springer Science and Business Media.

The percentage of essential amino acids in the entire amount of amino acids ranges from 8.6 to 9.3. The essential amino acid composition of buckwheat (Table 3.2) is more balanced and of better nutritional value than that of other cereals [25, 29]. Buckwheat is especially rich in lysine [27] and some minerals [30]. Leucine is the first limited amino acid [31].

Buckwheat is generally rich in vitamins and essential minerals. It is an important source of thiamine (vitamin $B_1$), riboflavin (vitamin $B_2$), and other vitamins from the B group, of which buckwheat acorns contain 150% more than wheat grain. Buckwheat contains natural antioxidant tocopherols (vitamins from the E group) and is also rich in vitamin P, which is found primarily in flavonoid rutin and is used to stop capillary bleeding [4].

Buckwheat mineral content is also favorable; it contains Fe, Zn, Mg, P, and more (Table 3.3) and 0.039 to 0.053 mg Se 100 $g^{-1}$ of seeds.

The buckwheat seed is rich in K and Zn in the albumin; Ca, Mg, and Mn in the globulin; and Na in the prolamin and glutenin [31].

#### *3.1.7.2 Health value*

Buckwheat is used as a dietary food for children and the ill; its nutritional and medical properties make it a useful and interesting seed to many people.

Buckwheat is also a highly effective nutritional food. Besides high-quality proteins, buckwheat seeds contain several components with healing benefits: flavonoids and flavones, phytosterols, fagopyrins, and thiamin-binding proteins [32]. Buckwheat product consumption can improve diabetes, obesity, hypertension, hypercholesterolemia, and constipation [33]. It can also prevent gangrene, frost bites, and strengthen the human organism after radiation. Buckwheat has been shown to reduce the caloric value of meals and preserve blood sugar at the optimal level [4]. Food from buckwheat flour is not toxic for people with celiac disease, because it does not contain protein gluten [34]; thus, it is often appreciated for its culinary properties.

***Table 3.3*** Comparison of Mineral Content Among Buckwheat, Corn, and Wheat

| Product | Amount (mg 100 $g^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ca | Fe | Mg | P | K | Na | Zn | Cu | Mn |
| Buckwheat[a] | 11.6–11.0 | 17.5–4.0 | 173–390 | 426–330 | – | – | – | – | 14.3–3.37 |
| Buckwheat[b] | – | – | – | – | – | – | 22.5–37.5 | 5.3–7.2 | 17.5–22.4 |
| Buckwheat flour[a] | 41 | 4 | 251 | 337 | 577 | 0 | 3.12 | 0.09 | 0.099 |
| Corn flour[c] | 6 | 3,45 | 127 | 241 | 287 | 35 | 1.82 | 0.193 | 0.498 |
| Wheat flour[c] | 15 | 1,17 | 22 | 108 | 107 | 2 | 0.70 | 0.144 | 0.682 |

[a] [7].

[b] [30].

[c] [24].

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As mentioned earlier, buckwheat is rich in vitamin P, a component of flavanoid rutin. Rutin has an anti-inflammatory, hypertensive effect; it reduces fragility of blood vessels associated with some coronary diseases [35], binds estrogenic receptors, and has antitumoral properties [36]. Flavanoids such as rutin and isovitexin have been found in groats, while hulls also contain isorientin, orientin, quarcetin, and vitexin [37]. Since flavanoids have an antioxidant effect, foods made with buckwheat can be used to prevent diseases. A buckwheat diet reduces blood pressure [38], reduces concentration of cholesterol in serum, helps with activity of the hamster's liver [39] and gallbladder, and suppresses the formation of gallstones [40]. Similar effects upon cholesterol, metabolism, and hypocholesterol were described by humans, most likely due to the soluble fiber content in buckwheat foods [41].

Prestamo et al. [42] conclude that buckwheat is a prebiotic and healthy food, because higher levels of lactic acid bacterias like *Lactobacillus plant arum* and *Bifidobacterium lactic Bifidobacterium* ssp. were found in buckwheat diets than conventional diets. By definition, prebiotic refers to a nondigestible food ingredient that beneficially affects the host and selectively stimulates the growth and activity of one (or a limited number of) bacteria in the colon. Asian countries typically have lower numbers of cardiovascular accidents and cancers than the occidental countries, and research on the subject [42] mainly attributes these numbers to the buckwheat diet, like the soba noodles commonly eaten in Japan. Deschner [43] and Liu [44] also report that buckwheat reduces cellular proliferation and therefore protects the colon against carcinogenesis.

Buckwheat has been described in recent scientific articles as a plant that causes various allergies, as a consequence of hypersensitivity to foreign proteins (anaphylaxis) [45]. Asthma attacks, gastrological problems, cold, eye problems, epileptic fits, and similar symptoms are mentioned most often. Food that contains fagopyrin may indeed cause skin inflammation (urticaria) in some people. But allergies may also be transferred through the air by thermostable proteins with high molecular mass. These proteins can cause so-called "baker's asthma," because flours are powders of varying degrees of fineness [46].

#### *3.1.7.3 Processing*

Products made from buckwheat are flour, hulled grains (groats often called kasha in English and sometimes known as buckwheat rice in Japan), processed dry, frozen, and instant buckwheat (soba) noodles, and hulls for pillows. Flour can be used as an additive when making chocolate, cream, cakes, canned meat and vegetable products, and breakfast cereals (Figure 3.2). In some countries, buckwheat is also used to prepare alcohol drinks. A developing technology applies the process of extraction to the production of snacks containing buckwheat flour. Buckwheat could be used to an even greater extent by processing cereals from hulled grains.

Buckwheat's technological value (thousand achene's weight, volume weight, proportion of fractions on sieves 4.5 and 4 mm, proportion of husks, and percentage of groats) can be influenced by weather (particularly rainfall) during flowering and achene formation periods [47], and also by genotype.

#### *3.1.7.4 Milling*

Flour processing is done by hand or by water-driven stone mills and grinding stones in buckwheat-growing countries. The old hand-driven or water-driven mills do not develop excessively high temperatures during the milling process, which results in the typically pleasant buckwheat taste; quick milling to flour, in contrast, causes long exposure to high temperatures, and the good taste is lost. Two main flour types are produced: the first from whole grains with separations of different flour fractions; and the second from hulled grains, where several types of broken endosperm are obtained as inner-layer endosperm, further classified in types. The characteristics of flours (flavor, masticating, overcooking, and so forth) will vary, depending on the flour type [2]. Fine (light) flour mainly contains endosperm. It is possible to get bran milling fractions from the seed coat and some embryo tissues [28]. It is also possible to separate 60 to 70 kg of flour of standard darkness quality from 100 kg of grains during milling; what remains are scales and bran. The production of fine (light) flour does not exceed 52%.

Traditional processing of buckwheat groats (kasha) (Figure 3.3) is based on dehusking grains after thermal treatment (mostly cooking and backing),


***Figure 3.2*** Buckwheat flakes.


***Figure 3.3*** Buckwheat groats (kasha).

similar to the autoclaving process. At high temperatures, drying grains start to open and need to be extruded mechanically, with the use of rough metal surfaces or rotating disks. New groats processing is based on (i) thermal treatments of grains or autoclave hulling in combination with high pressure or (ii) natural hulling of raw and dry grains (named "cold" processing). "Cold" processing is based on special, mainly secret technical solutions.

New food products can be developed from buckwheat by using modern hydrothermal technologies such as flaking, extrusion, and puffing. In bakery, pasta, and confectionary products, buckwheat flour does not contain any gluten; therefore, the elasticity and plasticity characteristics of its dough are not comparable to dough made from wheat flour [27]. As mentioned previously, a maximum of 30% buckwheat flour is recommended in a mixture for bread making. In producing confectionary products such as cakes, biscuits, and crackers, the lack of gluten and the rheological parameters of buckwheat do not cause any significant problems. Processing conditions — including tempering moisture, heating temperature, and heating time — significantly influence the physical and chemical qualities of buckwheat grit cakes, such as the volume, hardness, integrity, color, internal structure, and rutin content [48]. Buckwheat grain used to occasionally be distilled into alcohol, but today it is used in breweries for the production of high-quality beer.

## 3.2 Quinoa

### 3.2.1 Introduction

Quinoa, also known as quinua or white quinoa (*Chenopodium quinoa* Willd.),is becoming a more and more interesting organic food crop [49] due of its high nutritional value; it provides an exceptional combination of vitamins, minerals, high protein quality, and essential amino-acid composition. Quinoa is a native plant to the Andes Mountains. The grains and young leaves of quinoa have been consumed for many years by the people of the mountain regions of Bolivia, Chile, Ecuador, and Peru [49, 50]. In the Inca language, quinoa means "mother grain"; the quinoa plant has been an important staple food for centuries.

Quinoa cultivation began to decline in Andean countries with the development of intensive agriculture. The introduction of cereals such as barley and wheat brought cheaper products, due in part to mechanized harvesting and threshing processes. The cost to the farmers who were growing quinoa often did not justify their labor; thus, barley and wheat eventually replaced quinoa. At present, quinoa continues to be grown in Colombia, Ecuador, Peru, Bolivia, Chile, and Argentina.

Quinoa has been selected by FAO (1998) as one of the crops destined to solve the food security problems of the Andes during the twenty-first century, due to its nutritional qualities, cultural acceptability, increasing production, and marketability. The main producers and exporters of quinoa grain to Japan, Canada, and the EU are Bolivia and Peru, where the production of quinoa is still increasing. Bolivia produces an average of 47534 ha and 640 kg grain yield ha$^{-1}$, and Peru averaged 28355 ha with 920 kg grain yield ha$^{-1}$ in 1999. In recent years, the export price for grain has varied between 0.56 and 1.77 USD kg$^{-1}$, and the price for organically produced yield exported to Europe was 3.00 to 3.50 USD libra$^{-1}$ (lb = 0.45 kg). Quinoa is exported to the U.S. from the provinces of Buenos Aires and Córdoba in Argentina; around 500 hectares of quinoa are also grown within the U.S. (Colorado) as a commercial crop [51*].

* With permission from the Food and Agriculture Organization of the United Nations (FAO), authoroziation number A138/2005; Mujica, A. et al., Quinoa (*Chenopodium quinoa* Willd.): ancestral cultivo Andino, alimento del presente y futuro, project FAO presentation, Santiago, Chile, 2001, 303 pp.

Despite the extreme reduction in quinoa production, the interest in this food crop increased after 1975 and was experimentally produced in 22 countries outside South America until 1989, especially as fodder plants for animals in Europe. Some European countries, such as Great Britain, Spain, Denmark, Germany, Finland, and Slovenia, are studying its adaptation, breeding, and possibilities for commercial production [50].

## 3.2.2 Botany

### 3.2.2.1 Taxonomy

Quinoa (*Chenopodium quinoa*, tetraploid, 2n = 36) is an annual herbaceous plant and belongs to the family *Chenopodiaceae* (*C.* species may be diploid, tetraploid, hexaploid, or octoploid); beet (*Beta vulgaris* L.) and spinach (*Spinacea oleracea* L.) belong to the same family. The genus *Chenopodium* consists of 150 species, classified into 16 sections. Few plants from section *Chenopodium* are used for human consumption. Besides quinoa, *Chenopodium pallidicaule* Heller is produced in Peru; *Chenopodium berlandierri* Moq. ssp. *nuttalliae* Safford is produced in Bolivia; and *Chenopodium album* L. is cultivated in Himalaya as food crops. *C. album* (hexaploid) and *C. berladieri* are more known as weeds. *C. berlandieri* can cause breeding problems, because it is tetraploid and crosses readily with quinoa. Quinoa is the most important species from genus *Chenopodium*. In the first stage, cultivated genotypes originated from 6 ecotypes and 4 plant populations from different regions [50].

### 3.2.2.2 Morphology

Cultivated genotypes of quinoa exhibit great genetic diversity. Many differences exist among genotypes in plant height (from 0.2 to 3.0 m), the coloring of the plant, florescence and seeds, degree of stem branching, leaf morphology, types of inflorescence, seed weight, protein content, saponin content, calcium oxalate crystals in the leaves, and so forth. Most vegetative, floral, and yield characteristics are controlled by genetic factors, but they are also affected by environment and production.

Quinoa has a semivigorous and deep-rooting taproot with branched secondary and tertiary roots. The root depth and plant height represent equal portions. After emergence, the root elongation of young plants occurs quickly in the presence of adequate temperature and soil moisture. Ten weeks after sowing, the taproot depth remains shallow, perhaps reaching a depth of 30 cm, but this characteristic varies among genotypes. The root branches are formed just bellow the rootneck. Deep roots and branching may be one of the reasons for the high degree of drought resistance among quinoa plants.

Quinoa plants have upright stems, which form branched or unbranched plants, depending on genotype. In branched genotypes, the number of branches depends on climatic conditions and density of plant population. A high degree of branching is not undesirable for grain production, but an adequate grain yield is reachable under optimal relationships among plant population and plant branching for each growing condition. The lengths of branches, which originate from the axils of each leaf on the stem, vary few centimeters in length between the axils of the leaf and the top of the main stem or inflorescence. The outside of the stem and branches can be green, red, or yellow, with different-colored stripes, or green with colored axils (red or purple). In the early growth stages, the leaves are covered with granular bladdery excrescence, which passes on to white and purple color. A mature plant is pale yellow or red to purple in color. Leaves have different leaf laminae; lower laminae are mostly rhomboidal, while the upper leaves are triangular or lanceolate. Most often, the lamina is plane, but in some genotypes it can be undulating. The number of leaf serratations may vary from 0 to 20 teeth; in serrated genotypes, the upper leaves have fewer teeth (serratations). Leaf area varies depending on the position of the leaves on the plant, the genotype, and the plant population. Leaf area of middle leaves range from 19.0 to more than 50.0 $cm^2$, and between 3.0 and 10 $cm^2$ for upper leaves.

Quinoa has a recemose inflorescence (panicle) containing many different colors. Its branching depends on genotype (Figure 3.4), but in general, two types of inflorescences exist: lower inflorescence, or amaranthiform, where flowers (glumeruli) originate from secondary axes; and upper inflorescence, or glomerulate type, where groups of flowers originate from tertiary axes. The flowers are incomplete without petals. Quinoa is highly self-fertile, because most of its flowers are hermaphroditic, but they may also be female

***Figure 3.4*** Branches of quinoa.

(pistillate) or male sterile (usually with hybrids). The size of hermaphroditic flowers varies from 2 to 5 mm, and females grow up to 3 mm. Hermaphroditic flowers contain a five-numbered perigonium, a pistil, and an ellipsoid ovary, and the stamens have short filaments bearing basifixed anthers. Additionally, the style has two or three feathery stigmas. The female flowers have only perigonium and pistil [52].

The fruit is an achene, protected by the perigonium. Different colors in the inflorescences are caused by the coloration of the perigonium. The seeds are yellow, red, purple, brown, black, or white; colors are determined by the color of the pericarp, or by the episperm when the pericarp is translucent. The quinoa seed has an unusual structure; a medial longitudinal section showing the pericarp, hypocotyl-radicle, and cotyledons; endosperm in the micropylar part only; and radicle, funicle, shot apex, and perisperm [53]. Seeds vary in weight from 2 to 6 mg and in size from 1 to 2.6 mm, and they may be sharp, conical, cylindrical, or ellipsoidal. The seed mainly possesses sharp borders, but it can also have a rounded border.

### *3.2.3 Growth and Ecology*

According to summaries of different descriptions [51, 54, 55] and personal notices, the phenological stages of quinoa are:

1. Vegetative (V): Seed germination and emergence, true leaves formation (two, four, or six true leaves), and branching (first order branches at the second, third, and fourth nodes); and
2. Reproductive (R): Bud formation (covered, visible, and distinct in cm, shape), florescence or anthesis (onset, 50% and 100% flowering), and seed formation and maturity (woody seed, soft seed, or full mature seed).

The vegetation period from sowing to harvesting may last anywhere from 120 to 240 days [55], depending on genotype and growth stages, with the stage from two true leaves to bud formation lasting between 41 and 89 days; from bud formation to anthesis lasting between 7 and 53 days; and from anthesis to maturity lasting between 65 and 137 days [56]. The durations between the true leaves stage and bud formation and between seed formation and full maturity require the longest times. There are no significant differences among genotypes. Quinoa is a long-day plant, with significant influences on duration of vegetation periods. An optimal supply of nutrients may influence the transformation into vegetative stage even more [57].

Quinoa adapts easily to different topography and altitudes. It can be grown in adverse environmental conditions such as cold, soil salinity, drought, and humidity [50]. In dry years, water shortage may cause considerable yield reductions, but a minor draught stress does not result in a large yield decrease [58]. Dry periods in the true leaves stage can result in significantly smaller surfaces of side leaves, lower green and dry matter weights

*Figure 3.5* Research of different irrigation treatments affected growth in quinoa plants (from the University of Maribor).

of all leaves, lower inflorescence weights, lower root weights, and less branching in comparison to optimal conditions. Plants that follow later can partially compensate for a lack of humidity, which is a benefit for producers in dry areas (Figure 3.5) [59]. A noticeable production increase appeared in plants subjected to drought during the branching stage than during other growth stages [58]. Periods from full-field water capacity to complete dehydration of soil, when all water available to plants was used, varied according to the development stages of quinoa. The period was the longest at branching stage — where it lasted 16 days — and the shortest at flowering stage — where it lasted 6-days; a 10-day period was noted at the grain-filling stage [60].

Research shows that misestimations and poor knowledge regarding quinoa water demands caused damage, due to the overirrigation of plants. A lower irrigation degree of quinoa plants is recommended for the Altiplana region, whereas for cultures sensitive to drought and with higher water demands, increased irrigation is recommended [58]. Plants are most sensitive to cold in the early growth stages and can survive from –3 to –15°C, depending on the genotype's ontogenic resistance. Plants with red leaves are less sensitive to cold [50]. Acceptable production is also obtained in acid soils with a pH of 4.5 and alkine soils with a pH of up to 9.5, common for some Peruvian and Bolivian ecotypes, respectively. Production appears both in sandy and clay soils, but it prefers sandy-loam to loamy-sand and semi-deep soils with good drainage and nutrient supply. However, marginal agricultural soils, which have low natural fertility, poor drainage, and high acidity, are frequently used to grow quinoa [61].

## *3.2.4 Organic cultural practice*

### *3.2.4.1 Crop rotation, pests, and diseases*

With balanced biodiversity and suitable crop rotation, avoiding plants from the family *Chenopodiaceae*, quinoa should not require special pest and disease control. However, viruses found on spinach or beets have been observed in quinoa fields. Diseases caused by *Peronospora* sp., *Sclerotinium* sp., *Phoma* sp., *Botrytis* sp, and *Pseudomobas* sp. may have an influence on yielding [61]. Several species of cosmopolitan polyphagos insects (e.g., *Agrotis ipsilon* Hufnagel, Lepidoptera: nuctuidae) may cause economic losses in quinoa production. Some of widespread pests endemic to the Andean region may cause a 15 to 50% loss of yield, especially two species of moths (*Eursacca quinoae* Povolyny, *E. melanocampta* Meyrick) [62], which is a cause for developing new strategy of research [63]. Emerging plants may also be damaged by flea beatles and caterpillars. Quinoa is generally cultivated in rotation with potatoes and cereals. The quinoa seeds do not exhibit dormancy and they germinate when conditions are suitable; the plant itself though, in wild form, may remain in soil for 2 to 3 years without germinating [55].

### *3.2.4.2 Sowing and intercultural operations*

Grain yield appears to strongly depend on sowing density and date [49, 56, 64]; however, the recommended plant population varies a great deal worldwide. The best time for sowing and the rational sowing rate depend primarily on the climatic conditions prevailing in the given area. Applied sowing rate and the interrow and row distances also depend on the available mechanization for sowing, weeding, and cultivation. Quinoa can be sown early in spring when the soil temperatures range from 5 to 7°C; but plants grow slowly during the first 2 weeks following emergence. Early planting may contribute to effective control of pigweed and other summer weeds, since quinoa will have a good head start on growth before the weeds emerge.

Many different methods of sowing are used in quinoa-producing countries. The current recommendation calls for wide-row sowing with interrow spacing of 0.2 to 0.4 m or manual sowing in heaps of five seeds 0.4 m in diameter, and a distance between heaps of 0.7 to 1.2 m. According to some studies, the most suitable interrow spacing is 0.2 m with 20 kg of seed $ha^{-1}$. In this case, plants cover the soil surface within 45 days of sowing; this makes it possible to achieve optimal plant distribution and prevent high weed competitiveness [56]. Such sowing methods are usually less suitable due to a lack of weeding mechanization, especially in early growth stages. Interrow spacing should be adjusted to the available mechanization and can range from 0.4 to 0.7 m. An amount of seed higher than 20 kg of seed $ha^{-1}$ resulted in shorter plants; lower seed amounts resulted in the high branching of plants and earlier maturity. In South America, the suggested amount according to production conditions and available mechanization is 4 to 6 kg of seed $ha^{-1}$; elsewhere, 8 to 12 kg of seed $ha^{-1}$ or more are recommended. Mujica [55] suggests 15 to 20 kg unselected seed $ha^{-1}$. In humid conditions, plants may be weak with low seed production. The number of plants in experiments varies from 30 plants $m^{-2}$ [65] to an optimal plant population of 140 plants $m^{-2}$ in a greenhouse with controlled climatic and hydroponical conditions [66], to 200 plants $m^{-2}$ in the field trials [52]. For cultural practice, 100 to 150 plants $m^{-2}$ are suggested in the U.S. and about 800 seeds $m^{-2}$ to 2000 seeds $m^{-2}$ are suggested in South America [66].

Cultivation work, especially in furrows spaced 0.4 to 0.8 m apart, is limited to one or two hoeings during the first phonological phase. Organic fertilizers that are left over from the preceding crop or given stable manure in autumn provide adequate yielding in the organic production system. Due to lack of data about organic fertilization in quinoa, compensation is suggested by organic fertilizers at an application rate of about 120 kg of N $ha^{-1}$ [65, 67] for the expected enhancement of grain yield.

### *3.2.5 Harvesting*

Quinoa is physiologically mature when grains are dry and firm and we are unable to thresh them in hand. At the maturity stage, plants become lighter and more yellow, and the leaves fall off. Traditionally, plants were pulled or cut, and whole plants were dried. Now, the crop can be harvested using a combine; however, this should only be conducted with dry plants. There is no major loss of seed noted at harvest. A lot of damage can be caused by birds; in some test fields, they picked approximately 40% of produce. Usual harvest is 400 to 1200 kg grain yield $ha^{-1}$. Under experimental conditions, harvest reached as high as 435 to 6591 kg of grain yield $ha^{-1}$ [50].

### *3.2.6 Chemical composition, nutritional and health value*

The proximate composition of quinoa ranges from 10 to 18% for crude protein, from 54.1 to 64.2% for carbohydrates, from 4.5 to 8.75% for crude fat, from 2.1 to 4.9% for crude fiber, and from 2.4 to 3.65 for ash [68]. Compared data (Table 3.4) shows wide ranges, which are probably a reflection of differences among genotypes and growing conditions and their effects on protein-fat ratios in perisperm. However, the protein content is slightly higher [69], to 5% higher [70], than that of most other cereal grains. Some cultivars from Ecuador are very protein-rich. Additionally, the fat content is at least twice as high as in most cereals. Seed content comprises approximately 60% of starch from the total carbohydrates, and the remaining are mostly free sugars. Carbohydrates in quinoa seeds display some important physical and chemical properties, especially smaller starch grains within the size of 1 to 2 μm in comparison to corn (1 to 23 μm) and wheat (2 to 40 μm). Due to amylases and a high capability of water uptake, starch is extremely viscous and good for making starch paste [71*].

* European Patent Application, No. 891216554.1, 1989, With permission from European Copyright Office.

***Table 3.4*** Proximate Composition of Quinoa (%) According to Different Authors [72–74]

| Component | Fleming and Galwey [72] after Romer | Koziol [73] | Ruales [74] |
|---|---|---|---|
| | (Variation) | | |
| Moisture | 12.9 (5.4–20.4) | 9.6 | Dry |
| Protein | 14.3 (9.6–22.1) | 15.7 | 14.1 |
| Starch | 61.4 (46.0–77.4) | 61.7 | 51.6 |
| Fat | 4.6 (1.8–8.2) | 7.2 | 9.7 |
| Fiber | 3.0 (1.1–5.8) | 2.9 | 13.4 |
| Ash | 3.5 (2.4–9.7) | 3.3 | 3.4 |

*Source*: Reprinted from *Underutilized Crops: Cereals and Pseudocereals*, Fleming, J.E., Galwey, N.W., and Williams, J.T., Eds., Chapman & Hall, London, 1995, 3–85. Copyright (2006), with permission from Kluwer Academic Publishers.

*Source*: Reprinted from Koziol, M.J., *J. of Food Composition and Anal.*, 5, 35–68. Copyright 2005, with permission from Elsevier.

*Source*: Reprinted from Ruales, J., Development of an Infant Food from Quinoa (*Chenopodium quinoa*, Willd.): Technological Aspects and Nutritional Consequences, Ph.D. Thesis, University of Lund, Lund, Sweden. Copyright 2005, with permission from LUND University.

Proteins in quinoa seeds are mainly of the globulin and albumin types, without gluten fraction. Amino acid composition (Table 3.5), except for leucine, meets the ideal composition reference pattern for children, according to the FAO/WHO/UNU standards; additionally, 100 g of quinoa seeds meet 200% of adults' daily need for histidine, 337% of the need for isoleucine, 347% of the need for lysine, 312% of the need for methionine and cystine, 363% of the need for phenylalanine, 411% of the need for threonine, 180% of the need for tryptophane, and 346% of the need for valine.

Quinoa is rich in lysine, the first limiting essential amino acid in cereals. Seeds also contain high amounts of histidine, and the value of isoleucine and methionine + cystine is higher in comparison with other cereals [73].

The mineral content of quinoa grains varies, depending on cultivars and growing circumstances, but they are overall rich in phosphorus, magnesium, and calcium (Table 3.6), similar to cereals. The mineral content in the hull grains is a few times higher than in the dehulled grains and differs among milling fractions.

According to the recommendations of dietary allowance, quinoa can be classified as a source of tocopherols (vitamin E), riboflavin ($B_2$), thiamin (vitamin $B_1$), and folic acid. Unlike cereals, quinoa also contains vitamin C [69]. The content of alpha-tocopherol varies from 2.0 to 5.4 mg 100 $g^{-1}$ grain, thiamine from 0.3 to 0.4 mg 100 $g^{-1}$ grain, riboflavin from 0.2 to 0.4 mg 100 $g^{-1}$ grain, about 78 μg 100 $g^{-1}$ grain, and from 3.0 to 16.4 mg 100 $g^{-1}$ grain of vitamin C [78, 79]. The Ca:P ratio in quinoa is more suitable (1:1.25) than with cereals (1:10.7), considering thatthe optimal ration is 1:1.

Quinoa contains a less appropriate component in the pericarp of its seed, from a nutritional point of view, known as saponin. Saponin is a detergent

*Table 3.5* Essential Amino Acid Composition of Quinoa (g 100 $g^{-1}$ protein) According to Different Authors

| Amino Acid | Modified by Telleria et al. [75] Variation Among Four Cultivars | Koziol [73] | Becker and Hanners [76] |
|---|---|---|---|
| Histidine | 2.1–2.8 | 3.2 | 2.6 |
| Isoleucine | 2.4–3.8 | 4.4 | 3.7 |
| Leucine | 5.9–7.4 | 6.6 | 5.9 |
| Lysine | 5.1–6.7 | 6.1 | 5.6 |
| Methionine+cystine | 11.2–21.0 | 4.8 | 3.8 |
| Phenylalanine+ Tyrosine | 4.8–6.3 | 7.3 | 6.6 |
| Threonine | 2.9–4.1 | 3.8 | 3.5 |
| Tryptophan | 0.8–1.0 | 1.1 | – |
| Valine | 3.5–4.8 | 4.5 | 4.9 |

*Source:* Reprinted from *Archivos Latinoamericanos de Nutrition*, 28, Telleria, M., Sgrabieri, V.C., and Amaya, J., Evaluación quimica y biológica de la quinoa (Chenopodium quinoa Willd). Influencia de la extracción de las saponinas por tratamiento térmico, 253, Copyright (2006), with permission from ALAN.

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*Source*: Reprinted from Becker, R. and Hanners, G.D., *Food Sci. and Technol.*, 23, 441–444. Copyright 2005, with permission from Elsevier.

*Table 3.6* Mineral Content in Quinoa Grain and Milling Fractions

| Mineral | Whole Grain[a] | Whole Grain[b] | Whole Grain[c] | Flour[c] | Bran[c] |
|---|---|---|---|---|---|
| Phosphorus | 360 | 535 | 470 | 320 | 670 |
| Calcium | 110 | 87 | 190 | 150 | 240 |
| Potassium | 900 | 120 | 870 | 470 | 160 |
| Magnesium | 500 | 262 | 260 | 160 | 460 |
| Natrium | – | – | 1.1 | 6.7 | 0.6 |
| Iron | 9 | 8 | 2.0 | 1.8 | 2.5 |
| Copper | 1 | 1 | 0.7 | 0.6 | 0.8 |
| Manganese | 4 | 3 | 1.3 | 1.2 | 1.6 |
| Zinc | 0.8 | 3.6 | 0.5 | 0.5 | 0.8 |

[a] Chauhan et al. [77].

[b] Ruales and Nair [78].

[c] adapted by Taylor et al. [69] .

*Source*: Source: Reprinted from *Cereal Chem.*, 69, Chauhan, G.S., Eskin, N.A.M., and Thachuk, R., Nutrients and antinutrients in quinoa seed, 85, 1992, Copyright 2006, with permission from American Association of Cereal chemists.

*Source*: From Belton, P. and Taylor, J., *Pseudocereals and Less Common Cereals: Grain Properties and Potential*, 2002. Copyright 2005, with permission of Springer Science and Business Media.

*Source*: Reprinted from Ruales, J. and Nair, B.M., *Publ. Food Chem.*, 48, 131. Copyright 2005, with permission with Elsevier.

soluble in water and is found within plants in approximately 15 molecular forms. Saponin removed from grains represents natural substances used in organic soaps, detergents, shampoos, cosmetics, and so forth. These types of products may avoid water pollution after grain washing in the first step of food processing because some saponins are known to damage the intestinal membrane and reduce food consumption. However, saponin reduces the amount of cholesterol in the blood of people and birds. Some isolated saponins, found in many plants, may be used as natural insecticides that are harmless to mammals.

Chickpeas contain higher levels of saponin than quinoa, while spinach, asparagus, parsley, garlic, onion, and many legumes contain lower levels. Possible saponin bitterness is the major problem with consuming quinoa grains. In terms of total saponins, values in the region of 0.9 [78] to 1.4 g 100 $g^{-1}$ [80] have been reported for bitter types. Quinoa containing 0.11 g 100 $g^{-1}$ of saponin or less can be considered sweet [69]. Quinoa seeds contain trypsin inhibitors in the range of 1.4 to 5.0 TIU (trypsin inhibitory units $mg^{-1}$ of seeds), but trypsin inhibitory activity may be absent [78]. These values are considerably lower in comparison to beans (12.9 to 14.8 TIU $mg^{-1}$ of seeds) and soya, however (24.5 TIU $mg^{-1}$ of seeds), and these inhibitors can be inactivated through the process of cooking. Soya seeds also contain phytic acid, which forms insoluble complexes with multivalent cations ($Ca^{2+}$, $Fe^{2+}$, $Fe^{3+}$ in $Zn^{2+}$) and consequently reduces their biological value. Present substances are also found in other types of food. In order not to present major hindrances to the use of quinoa, popular opinion asserts that it is possible to reduce or even eliminate these substances by selection and still preserve the high content of amino acids.

Quinoa is suitable for people with celiac disease because it does not contain gluten.

### 3.2.7 Gastronomy and suggestions for homemade food

Quinoa is very useful in a wide variety of foods. Traditionally, quinoa flour has been used for coarse-grained bread called *krispina* [81] and can also be fermented to make a beer called *chicha* [82]. Based on these traditions, the whole grains are used for soups, stews, and broths. Whole grains are also suitable for replacing rice-like products, and the coarse fractions of milling can be made into porridge, flakes, and puffed grains. Today, quinoa flour is often added to wheat flour to prepare food like breads, tortillas, cookies, salads, and pancakes. Many culinary ideas for preparing dishes based on quinoa are available on the Web.

### 3.2.8 Processing

Food processing from quinoa grains is developed and described [49], but for declared organic products, adaptations should be made according to organic food processing standards. The first step in processing is the washing or abrasion of pericarp, or their combination, due to the removal of saponins from the grains or flour. The combination of dry abrasive polishing and washing seems to be most effective, because losses of nutritive substances are minimized [77, 78].

Quinoa grain is often milled whole due to its very small grain size. Whole grain flour may include some or no pericarp if the pericarp was removed by abrasion, or it may include pericarp if the saponins from grains were washed before milling. Using the roller mill makes it possible to reduce quinoa grains into bran and flour fraction. The bran fraction is very rich in protein (usually more than 20%), because the bran consists mainly of embryo [50].

An industrial approach based on gun puffing, extrusion cooking, and expanded snack-type products [69] like flafes and poppies (Figure 3.2.1) is appropriate for organic food processing. This approach also makes it possible to prepare quinoa porridge flour [83], gluten-free pasta [84], or malted grain flour called "power" flour [85]. Quinoa instant infant porridge meets the energy requirements for children and contains about 16% proteins with a 95% rich digestibility rate [69].

Quinoa flour has been used to make leavened bread only as a 5% addition to wheat flour, because quinoa does not contain gluten. If a higher percentage of quinoa flour is added, the effect of the small-size starches and their amylase activity will result in very poor loaf volume. Good experiences are reported when preparing cakes [86] and cookies [87]. Cookies with an additional 20% of quinoa flour and cakes with up to 10% of quinoa flour have a delicious nutty taste.

## 3.3 *Grain amaranths*

### 3.3.1 *Introduction*

Since the 1970s, grain amaranths have been attracting increased attention due to the importance of their rich nutritional compounds to human nutrition. Grain amaranths are a small group from the genus *Amaranthus*, with more than 60 existing species. Plants are cosmopolitan, with extreme genetic diversity consisting of mostly weed amaranth species. The center of this biodiversity is central South America, containing numerous species, where they began with the cultivation of some species (*Amaranthus cruentus* L., *A. hypochondriacus* L., *A. caudatus* L.). Amaranth was one of the five irreplaceable food sources of the Aztecs in pre-Colombian Central American civilization. They grew it mostly in the Anahuac valley, but the colonization period reduced its production.

Amaranth, or huautli, also carried religious and agronomical importance besides its nutritional value. From water and amaranth, the atole drink was produced, grain was milled into flour (uauhatolli), and goudh from the flour was filled with leaves and prepared as an amaranth plate (huauquillamalmaliztli, translated as: a dish of bledos, prince's father tamales). For religious purposes, special figurines were made out of flour and honey. The shapes and sizes of the figurines depended on monthly rituals and varied from small pyramids to large images of mountain divinities. Those idols were carried around, and pieces of them were eventually eaten. To the colonizers, these rituals resembled Christian Eucharistic ceremonies; accordingly, they halted the amaranth production and banned its consumption. Amaranth was replaced by other cereals from the Old World, poverty became viewed as a negative status symbol, and amaranth's taste and religious connotations began to cause disapproval [88*, 89**].

Above all others, *A. caudatus* L. is considered the primary crop among South American civilizations. In the precolonization, period it was produced in Equador (where it was known as ataco and sangoracha), Bolivia (coimi, millmi), Peru (achiata, achos, achis, incajataco, coimi, kiwicha) [90], and Argentina. Amaranth's moisture was most significant to the Andes farmers. Amaranth is also used as an ornamental plant, a vegetable, in medicine, for feed use, and as a component in the cosmetic industry [88].

Commercial cultivation of amaranth for human nutrition does take place. In many developed countries, including the U.S. and some European countries, the amaranth's use has been extendedmainly to rich nutritional food produced under ecological–organic production systems.

### *3.3.2 Botany of grain amaranths*

Amaranth is a pseudocereal, assigned to the family of dicotyledonous *Amaranthaceae*. Many species from genus *Amaranthus* should be used like a grain pseudocereal; according to grain potential and breeding programs, the following three species are the leading ones:

- Bush greens, red amaranth, huautli (*Amaranthus cruentus* L., sin. *A. paniculatus* L.);
- Prince's feather (*Amaranthus hypochondriacus* L.);
- Love-lies-bleeding, Inca wheat, cat-tail, tumbleweed, Omca wheat, Quihuicha, tassel flower (*Amaranthus caudatus* L.).

Amaranth is an annual plant. The height of plants differs among the species and according to the ecological circumstances and production systems. The plants range in height from a few centimeters to 3.5 (4) meters. They have a taproot and well-developed lateral roots, and leaves are elliptical or egg-shaped and notched at the tip of the leaf blade. Inflorescence levels differ among species. In general, the amaranth seeds are relatively light and small

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** Reprinted from Cultivated grain amaranths, in *Nekatere zapostavljene in/ali nove poljščine (Some disregarded and/or new field crops)*, Bavec, F., Univerza v Mariboru, Fakulteta za kmetijstvo, Maribor, 2000, 141.

with diameters of about 1 mm. With regard to *A. hypochondriacus,* inflorescence is large and branched and of a unified green or red color. Its numerous flowers contain sharp and rough bracts. The seed coat of amaranth is smooth and thin; thus, the seeds can be used directly in most cases.

The structure of the mature seed consists of a peripheric embryo surrounding the nutritive tissue, which is called a perisperm. Endosperm remnants are close to the root tip. The embryo encloses the starch-rich perisperm like a ring, and the percentage of embryo weight is about 25% of the grain weight. Inside the embryo a differentiation of the three primary meristematic tissues appears: the procambium appears as a single bundle in the embryonic axis or as small bundles throughout the cotyledon's length; these provascular cells are small and elongated and with fewer reserves and more cellular organelles than the large protoderm and ground meristem cells. These latter cells have more protein bodies, and they show a higher number of larger globoid crystal inclusions than the others. The perisperm is a starchy tissue, and its cells have thin walls and are full of angular starch grains [91*].

The plants of *A. cruentus* grow up to 180 cm tall. Inflorescence is green or red, sometimes spotty and soft, with bracts gentle that are to the touch (Figure 3.6). Seeds appear in various colors. The same can be said about the colors of inflorescence, which, in most cases, appear to be straighter than *A. hypochondriacus.*

*A. caudatus*, originally from Andes, is a plant that grows between 0.4 and 3.0 m tall. Leaves are attached with petioles, apposite or alternate, of a green to purple violet color. Inflorescence (Figure 3.6) can be classified from straight to horizontal, with lively colors including green, yellow, orange, pink, red, violet, and brown. Flowers are small. Male flowers consist of three to five stamina, and female flowers contain a superior ovary with one seed. Seeds are very small, only growing from 1 to 1.5 mm in diameter, and are mostly white (sometimes yellowish, reddish or black) and smooth. The 1000 to 3000 grain weight equals 1 g. In general, plants intended for grain production have lighter grain, whereas the grain of plants intended for vegetable production is darker. The level of allogamy in flowers is 10 to 50%. Cross-fertilization depends on wind, insects, pollen production, and so forth, andseeds mostly do not undergo dormancy.

In all analyzed characters (seed yield, stand density and height, and 1000 seed weight), there were more marked differences between *A. hypochondriacus* varieties and *A. cruentus* varieties [92].

### 3.3.3 Ecology

Amaranths perform photosynthesis via $C_4$ pathway. This characteristic allows for the responsible and efficient use of low concentrations of carbon dioxide by fixing in the chloroplasts of specialized cells surrounding the leaf

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***Figure 3.6*** Inflorescence of *A. caudatus*.

vascular bundles, and also results in low losses by transpiration in association with stomata and osmotic adjustment. This characteristic enables amaranths to achieve active photosynthesis at high temperatures with a tolerance to lack of water.

In general, short day illumination is most suitable for *A. caudatus*, although it is well adapted to all growth conditions. It flowers even with 12 to 16 hours of day illumination [88]. In all grain amaranth species, a light regime with 12 hours of illumination gave the highest percentage of live seed emergence [93].

Water demands vary from 400 to 800 mm, and acceptable production is possible with only 250 mm of precipitation. Amaranth is a potentially useful crop in regions where soil moisture conditions vary considerably among growing seasons, due to its apparent ability to respond to water stress by increasing rooting depth. Maximum effective rooting depth of soil water extraction varies from 122 cm in less water-stressed years to 154 cm in more stressed years, occurring at early to late anthesis stages [94]. Highest amounts of water are required at the stage of seed emergence, germination, and flowering; during other stages, formed plants are tolerant to drought. Plants also adapt to moisture with more than 1000 mm of precipitation annually. Under dry conditions, approximately 70 to 75% of total water use (267 mm) occurred by the end of anthesis [94]. However, the year x genotype interaction is often significant for water use efficiency, plant height, plant aboveground biomass, grain yield, and harvest index.

The percentage of live seed emergence was above 80% in temperatures that exceeded 21°C [93]; in hybrid *A. hypochondriacus* x *A. hybridus*, the same percentage was achieved in temperatures that only exceeded 16°C [95]. The germination speed was closely related to temperature and decreased with decreasing temperature. Young plants are sensitive to warm temperature; during the branching stage, they can tolerate only up to 4°C. Unusually cool years and late sowing dates can result in plants not maturing before the first frost [96]. The maximum temperature for growth and development falls between 35 and 40°C.

## 3.3.4 Disposition for organic cultural practice

### 3.3.4.1 Growth patterns

Amaranth grows well in light sandy soils with high nutrient content. Soil should be airy or well drained. Suitable pH is from 6 to 7, but it also grows in extremely alkaline or acidic soil, which indicates tolerance to aluminum toxicity.

Regardless of the source of genetic material and its adaptation (South America, Central America, Russia, and Asia), the growth period from sowing to technological maturity lasts an average of 4 months; the wider range is from 105 to 160 days, which can be compared to the growth period of corn. However, an understanding of crop response to planting date is essential when evaluating a potential new crop like grain amaranths. Generally, the 48 accessions of *Amaranthus caudatus* L., *A. cruentus* L., and *A. hypochondriacus* L. in the Brazilian Savannah flowered 45 days after emergence, and the plants were harvested after 90 to 100 days [97]. The *A. cruentus* BRS Alegria, originated from mass selection in the variety AM 5189 of the U.S., gave in double-cropping — after soybeans — an average yield of 2359 kg grain $ha^{-1}$ and 5650 kg $ha^{-1}$ for total biomass, in 90 days from emergence to maturity [98].

### 3.3.4.2 Cultivation systems

According to the traditional production praxis of Central and South American countries, there are many acceptable production techniques that can be used in organic agriculture. Acceptable techniques include the following: direct sowing, sowing into classic seedbeds, the planting of seedlings, intercropped sowing with corn, sowing in bands separated from other crops, sowing at the edges of fields, and sowing as ornamental plants or as an extensive crop [99]. Using monoculture practice, which ignores the traditional agricultural practice, is not allowed in organic agriculture. For an organic agriculture practice, we suggest the inclusion of amaranths in the crop rotation every 3 to 5 years.

On a proper seedbed or in case of direct seeding, we need 4 to 6 kg of selected seed $ha^{-1}$. Row spacing should be around 0.8 m; Jamriska [92] found that the stands with narrower row spacing (12.5 cm) produced, on the average, higher yields than the stands with wider row spacing (0.5 m). According to our own experiences, the target population in Slovenia is 40 plants $m^{-2}$. We usually recommend sowing from 150 to 200 seeds $m^{-2}$ and manual thinning after emergence to achieve a final density of 29 to 52 plants $m^{-2}$.

The main effect of row spacing on grain yield was not significant, but the interaction of row spacing, plant population, and environment indicated population yield ranking differences at the 30-cm row spacing but not at the 76-cm row spacing [96]. Considering the analyses of yield, plant mortality, and potential harvest difficulties, the moderate population (173000 plants $ha^{-1}$), 76-cm row spacing, and generally higher-yielding *A. cruentus* cultivars would be recommended above 30-cm row spacing and populations of 74000 and 272000 plants $ha^{-1}$ [97].

Seed storage lasting more than 1 year decreased the percentage of germination. An early harvest of homogenous and dense amaranth crops is recommended for amaranth seed [95]. According to Bavec and Grobelnik [93*], a sowing depth of 15 mm gave the highest seedling weight on sand and the highest percentage of live seed emergence on loam with all investigated species (*Amaranthus mantegazzianus*, *A. hypochondriacus*, *A. cruentus*, and *A. caudatus*). On the sandy loam, the percentage of live seed emergence was not affected by sowing depth up to 15 mm. *A. caudatus* gave the highest percentage of live seed emergence, whereas *A. cruentus* gave the lowest percentage but the heaviest seedlings. Percentage of live seed emergence was severely reduced on the loam where topsoil crusting occurred after a decrease in soil moisture content from field capacity ranging from –60 to –70 kPa, but not on the silt loam even when dry conditions were maintained throughout the experiment. At 0.5-cm sowing depth, high moisture (10 to 20 kPa) did not influence emergence [100].

Amaranth crop provision is similar to corn: all nutrients should be easily available. Organic fertilizers, plowing under, or harvesting remains are necessary for sufficient nutrient supply. Although amaranth yield is responsive to available nitrogen in the soil, a high level of available nitrogen can negatively affect grain harvest in terms of excessive plant height, increased lodging, and delayed crop maturity [101].

Weeding needs to be performed at least twice: for the interrow space of emerged plants and when the plants are 15 to 25 cm high. In cases of natural land dominated by *Pennisetum purpureum* L., weeding performed two to four times is optimal for growth and development of grain amaranths. Weeding two times at 2 and 5 weeks after transplanting is optimal for growth parameters (plant height, leaf number, and shoot fresh weight); weeding three times at 2, 5, and 8 weeks after transplanting is optimal for shoot dry weight

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and grain yield; and weeding four times at 2, 5, 8, and 11 weeks after transplanting is optimal for grain protein content [102*].

### 3.3.5 Harvesting and yielding

Harvesting takes place before the plant reaches full maturity. The appropriate harvesting period is indicated by the yellowing of bottom leaves and dry seed. In traditional amaranth production, manually harvested plants cut 20 cm tall are tied into 15 to 20 plant sheaves. They are dried for a couple of weeks until leaves and stems are completely dry. Threshing used to be described as traditional "dancing" in some civilizations; people walked on dry sheaves and later cleaned the product by blowing into their open palms filled with seeds. Threshing may also be performed mechanically by seed-cleaning machines. In literature on the subject, we find optimistic predictions regarding the adjustment of cereal combines for the harvesting of amaranth due to modern technical advances.

Estimations of amaranth yield vary. Data on yields from the U.S. range from 800 to 1500 kg seed $ha^{-1}$; in Peru, from 2000 to 5000 kg seed $ha^{-1}$; and in Bolivia, from 900 to 4000 kg seed $ha^{-1}$. Green matter yield of American cultivars in southern Germany reached 1300 g $m^{-2}$ with cereal index below 30, and seed loss with manual harvesting was approximately 30% [103]. Studies of 15 cultivars of different species (*A. cruentus, A. hypochondriacus, A. hybridus*) of various origins grown in central European conditions showed yields from 1 to 270 g of seed dry matter $m^{-2}$ and from 290 to 1440 g $m^{-2}$ aboveground dry seed matter [104].

Storage facilities must be dry and airy. In proper conditions, seeds can remain in storage for more than 10 years. The data for transportation and storage recommends a moisture level below 14% in the seeds. Data described by Abalone et al. [105] found that when moisture content changed from 7.7 to 43.9% dry base, true density decreased from 1390 to 1320 kg $m^3$, bulk density from 840 to 720 kg $m^3$, specific volume increased from 0.78 to 1.10 $\times 10^3$ $m^3$ $kg^1$, and porosity ranged from 0.40 to 0.45.

### 3.3.6 Nutritional value

It is difficult to classify amaranth as food. According to general nutritional divisiona of food into carbohydrates (cereals, tubers), proteins (legumes and other nutrient sources), and minerals and vitamins (fruits and vegetables), amaranth leaves can be considered a vegetable, its grain is a rich source of carbohydrates, and its protein content is 12 to 16% (according to U.S. data). Lysine, methionine, cisteine, and arginine were found in the wholemeal of amaranth, while corn, barley, and common wheat proved to be poor in methionine and lysine [106]. Chemical scores of essential amino acids and essential amino acid in grain amaranths show the favorable nutritional

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quality of amaranth protein, which is almost comparable with egg protein. The relatively high content of essential amino acids in amaranth grain predetermines its use as a substitution of meat-and-bone meals [107].

The poor methionine and lysine content of common wheat could be supplemented mostly by adding the wholemeal of amaranth [106]. In 15 cultivars of prevailing species in central Europe, protein content of 13.3 to 17.9% in seeds was achieved. Muchova et al. [108*] compared all grain amaranth species and determined the highest content of the crude protein for *A. cruentus* (17.2% on average), whereas the lowest was *A. hypochondriacus* (15.72% on average). The starch contents were 543 in *A. caudatus* and 623 g $kg^{-1}$ in *A. cruentus*, while crude protein contents were 154 and 169 g $kg^{-1}$, respectively [109**].

Grain amaranth has been suggested as an alternative natural source of oil and squalene. The oil contents of grain amaranth are low (from 5.1% to 7.7%) as compared to other oil-containing grains; high concentrations of squalene were found in total lipids, ranging from 3.6% to 6.1%. The major fatty acids in amaranth oil consist of palmitic acid (19.1–23.4%), oleic acid (18.7–38.9%), and linoleic acid (36.7–55.9%) [110***].

Differential milling of amaranth yields three granulometric fractions as follows: high-fiber fraction, high-protein fraction, and high-starch semolina. The high-fiber fraction contains 63.9% insoluble fiber and 6.86% soluble fiber [111].

Protein fraction distribution in milling and screened physical fractions showed that the 30 mesh sample contained 2.34 fat and 9.05% protein, while the 40 mesh contained 16.18% fat and 26.46% protein [112].

### *3.3.7 Food processing*

Twelve groups of food from amaranths and 12 processes (cooking, puffing or popping, milling, milling in classification, cooking and flaking, drum drying, cooking extrusion, cooking extrusion and milling, cooking extrusion and flaking, germination – malting, direct starch hydrolysis, and starch isolation) are described by Berghofer and Schoenlechner [113], but some of them need to be adapted according to organic food guidelines and standards.

As a rule, the seeds are hard and the flower is very useful. Whole seeds can also be prepared. More than 50 ways of preparing amaranths for food are known. Leaves are still used in salads, soups, creams, desserts, drinks, and bread, and cakes are made out of seeds; additionally, organic cereals are now consumed in Austria. When making bread, 20% of flour is usually

* Muchova, Z., Cukova, L., and Mucha, R., Seed protein fractions of amaranth (*Amaranthus* sp.), *Rost. Vyroba*, 46 (7), 331, 2000.

** Reprinted from *J. Sci. Food Agric.*, 84 (10), Gamel, T.H., Nutritional study of raw and popped seed proteins of *Amaranthus caudatus* L and *Amaranthus cruentus* L., 1153, Copyright 2005, with permission from Elsevier.

*** Reprinted from *J. Agric. Food. Chem.*, 50 (2), He, H.P. et al., Extraction and purification of squalene from Amaranthus grain, 368, Copyright 2005, with permission from Elsevier.

substituted. Substitution of 10% and 15% (on weight base) wheat flour by amaranth flour has a positive effect on dough quality (increased binding of flour, better dough processing), the amount of produced $CO_2$ (increased), porosity of bread inside (more regular with softer pores), and nutritive value of products (increased). A considerably decreased gluten content and a negative effect on dough quality (adhesiveness) and bread (very low specific volume, considerable amaranth flavor) for 20% (on weight base) substitution of wheat flour by amaranth flour was found by Burisova et al. [114].

Grain amaranth has unique microcrystalline starch granules (1 to 3 mm in diameter). Pearled and unpearled *A. cruentus* seed was wet-milled using a high-alkaline, batch-steeping process and separation methods common to laboratory wet-milling of corn. Starch with a purity of 0.2% protein was obtained from both the pearled and unpearled amaranth. However, more starch was recovered from unpearled amaranth because of the leaching of fine starch granules during steeping. Less germ was recovered using unpearled amaranth [115*].

The share of the glutelins ranged (on average) from 15.45% for *A. hypochondriacus* to 20.63% for *A. cruentus*. The observed differences between the pairs of the species were all highly statistically significant, except for the difference between *A. caudatus* and *A. cruentus*, which was only somewhat significant, and between *A. hypochondriacus* and *A. paniculatus*, which was not significant at all. In relation to the percentages of the nutritionally important protein fractions (i.e., albumins + globulins + insoluble remnants) to the nutritionally least important prolamins fraction, we can line the nutritional value of the studied species up in the following order: *A. paniculatus, A, caudatus, A. cruentus,* and *A. hypochondriacus* [108].

Several treatments, including cooking, popping, germination, and flour air classification, mainly affected the protein and starch properties [109]. Heat treatment by seed popping at 170 to 190°C for 30 seconds resulted in significantly ($P < 0.05$) decreased valine and leucine contents. High contents of lysine and arginin were detected in both heat-treated and untreated grains, as well as satisfactory content of cysteine and lower levels of methionine, valine, lysine, and leucine. The latter three amino acids appear as limiting [107]. After popping, the true protein content in *A. caudatus* and *A. cruentus* decreased by 9 and 13%, respectively. Among the amino acids, the loss of tyrosine due to the popping effect was the highest, followed by phenylalanine and methionine. Leucine was the first limiting amino acid in the raw samples, followed by lysine, while the reverse order was observed in the popped samples [109].

Seed and flour can be used for making chocolate powder, syrups, and cakes. The study conducted on using green parts for natural organic dyes did not provide promising results.

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***Figure 3.7*** Breakfast made from amaranth seeds.

Amaranth flour has been found suitable for pasta products with excellent cooking and sensory properties [116]. Results suggest that for at least the soaking temperatures above 64°C, the absorption process of water is controlled by water–starch reactivity [117]. Without emulsifier, the production of pasta products was not possible [116]; however, emulsifier should be permitted for organic food processing.

Amaranth (*Amaranthus caudatus* L.) extrusion produced a highly acceptable snack product based on amaranth grains and flour (Figure 3.7). The most expanded products also had the best textures and were obtained at 150°C and 15% moisture. These conditions resulted in greater expansion, greater shearing force of extrudates, greater extrudate surface area per unit weight, and reduced shearing stress at maximum shearing force [118*]. A processing method for producing a high-protein flour and maltodextrins from whole amaranth flour was developed. The protein-enriched flour (31% of protein) may be used as a dry milk extender [119].

The new option in food processing might be a protein concentrate from amaranths described by Escudero et al. [120]. In cases when the flour protein content was 16.6 g% while that of the concentrate was 52.56 g%. According to the amino acid composition suggested from FAO indicated that the concentrate does not have limiting amino acids. The content of lysine was high in both the flour and the concentrate, making these products particularly useful as complements to cereal flour, which is deficient in this amino acid. The content of the soluble dietary fiber with a hypolipemic function was notably higher in the protein concentrate (12.90 g%) than in the seed flour (4.29 g%). The protein concentrate also exhibited a higher content of insoluble dietary fiber. The flour and the concentrate contain 75.44 and 56.95% of

* Reprinted from *J. Food Sci.*, 65 (6), Chavez-Jauregui, R.N., Silva M.E.M.P., and Areas, J.A.G., Extrusion cooking process for amaranth (*Amaranthus caudatus* L.), 1009, 2000, Copyright 2006, with permission from the Institute of Food Technologists.

unsaturated fatty acids, respectively. Squalene was detected both in the flour and the concentrate oils, with a higher content in the concentrate (9.53%) than the flour (6.23%). The presence of trypsin inhibitors, saponins, and phytic acid in the concentrate favor the metabolism of lipids; Escudero et al. [120] speculate that consumption of the concentrate might actually reduce the risk of heart disease. Also, combining the fractions rich in squalene gave a special 94% squalene concentrate [110].

### 3.3.8 Health value

Amaranths constitute an alternative source of proteins in the human diet, with advantages over animal proteins because of their low content of saturated fats and absence of cholesterol [120]. The amaranth grains, with excellent protein quality, can also be used in gluten-free special diets, especially for children.

Analyses proved that inclusion of amaranths in nutrition positively influenced hemoglobin or prevented blood anemia. The inclusion of amaranth in everyday diets can help avoid $FeSO_4$ diets due to 61% of biological acceptability of Fe from *A. hypochondriacus*. From this point of view, green leaves are also a quality vegetable [121].

The most important constituent of amaranth is squalene (affects biosynthesis of cholesterol), which, until the present time, was extracted from the livers of whales and sharks. Introduction of this plant to food products acts prophylactically, i.e., it appears to possess antisclerotic properties and combat constipation. This latter property may be used in the prophylaxis against cancer [122].

## 3.4. Wild rice

### 3.4.1 Introduction

Wild rice, also called indian rice and canadian rice (*Zizania palustris* L. and *Z. aquatiaca* L.), was a staple food for indigenous North Americans and arriving Europeans for thousands of years. It has also been cultivated in temperate regions of Asia. Interest in rice production is growing all over the world; production possibilities have been researched by both the Japanese [123] and Finns [124]. The plant is an aquatic grass that grows naturally in lakes and slowly flowing rivers, i.e., in moderately soft and acidic freshwater wetlands. However, for organic production, contaminated water without environmentally dangerous compounds is essential.

### 3.4.2 Biology

Within *Zizania* genus, modern taxonomists distinguish four wild rice species (*Zizania latifolia* [Griseb.] Turcz. & Stapf, *Z. texana* Hitchock, *Z. aquatica* L., and *Z. palustris* L.). *Zizania palustris* L. var. *palustris* (0.5 to 1.5 m high plants) and var. interior (0.9 to 3.0 m high plants) have the highest commercial value.

The florescence is a terminal panicle with male spikelets in the lower branches and female spikelets in the upper branches; the spikelets involve the formation of staminate and pistillate floral primordia. The frequency of plants with hermaphroditic floret formation ranged from 27% in the pistillate population (*Z. palustris*) to 70% in the Peterson Pond (*Z. aquatica*) population [125, 126].

## 3.4.3 Growth and cultivation

Production of wild rice has many specific characteristics, especially due to its biological, physiological, and postharvest possibilities. Its main characteristic is that the plant is produced on the paddies of the flooded fields with high organic content in the soils, with pH ranging from 5.8 to 7.8. The water depth in the rice paddies should vary between 0.2 and 0.6 m. The common seeding method in the new paddies involves broadcasting the seed at a rate of 30 to 50 kg viable seed $ha^{-1}$. In natural stands, the seeds mature in the autumn and pass the winter on the flooded paddy bed, where they reseed themselves. The highest yielding plant population does not exceed approximately 10 plants $m^{-2}$.

In natural stands, the seeds mature in the autumn and pass the winter on the lake bed. They germinate in the spring, with growth to maturity requiring approximately 100 days. Japanese research [123] found that seedling growth was much better in plants grown at 20°C than those at grown at 12°C, but there were no interactions between these temperatures and planting in water depths of 2, 6, and 8 cm, suggesting that temperature is an independent factor of water depth [123].

Because the plant is an aquatic grass, it grows in artificially flooded paddies, margins of lakes, and slowly flowing rivers and brooks; in the long term, the balance of nutrients may be affected by straw after harvest and complete decomposition may require 3 years.

Harvest maturity is reached when approximately one-third of the seeds are dark-colored and possess about 40% moisture. To protect natural stands in the state of Minnesota since 1939, the law has provided that wild rice in public waters can be harvested only by hand [127]. Today, combines or other mechanical harvesters are used for harvesting. If an aquatic weed harvester were used to remove standing straw from part of a wild rice stand at the end of the growing season, no difference would be noted in rates of organic matter decomposition or nutrient release between the chopped and unchopped straw [128].

## 3.4.4 Nutritional value and utilization

The protein content of wild rice is between 12 and 15%. It is important that wild rice contain 3.8 to 4.2% of lysine within the entire protein content; as such, wild rice contains twice as much lysine as other lysine-deficient cereals. Even lysine maize hybrids contain less lysine than wild rice. Wild rice contains more iron and zinc than brown or white polished rice and other cereals, as well.

Antioxidants have been isolated from wild rice seeds [129]. The high concentrations of iron (2.0–9.7 mg 100 $g^{-1}$ dry weight), copper (0.2–1.3 mg 100 $g^{-1}$ dry weight), and zinc (0.1–0.4 mg 100 $g^{-1}$ dry weight) in 26 brands of wild rice suggest that wild rice may be a good dietary source of these essential elements [130].

The grain yield varies from just a few hundred kilograms to 1250 kg $ha^{-1}$ in commercial paddies. However, organically produced plants, especially in commercial wild rice production areas, can be attacked by several plant diseases causes by fungal brown spot (*Bipoolaris oryze* and *B. sorokiniana*), stem rot (*Helmintosporium sigmoidinum* and *Sclerotinium* sp.), leaf smut (*Entyloma lineatum*), ergots (*Claviceps purpurea*) [131], *Phythophthora erythroseptica* [132], and insect pest (*Apamea apamiformis*) [133].

Wild rice production is a promising approach in some environments to the reduction of pests and diseases. Common rice in the free market belongs to the food most often treated with pesticides due to monoculture production in export countries. In the U.S. and Canada, wild rice is often grown and sold as an organic food and processed product; many producer and seller associations have been established for this purpose. Organic wild rice is the food that has spread the farthest among organic shops throughout the world. Food is prepared from wild rice by cooking the grains in boiled and salted water (with possible variations in water levels) for 25 to 35 minutes, bringing it to a simmer, and leaving it covered for 5 minutes with the heat turned off. The boiling times may vary according to the desired. However, wild rice is extremely versatile, allowing every cook vast opportunities to feature his or her culinary talents. Preparing food based on sole or prevailing compounds of wild rice grains — such as soups, salads, sweets, and side dishes — is a special pleasure and can be very tasty. For this reason, the popularity of wild rice is steadily increasing. Many recipes for innovative cooks are currently available on the Web.

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