chapter six

Alternative fiber, root, and tuber crops

6.1 Industrial and edible-seed hemp

6.1.1 Introduction

6.1.1.1 History

A historical review of hemp (*Cannabis sativa* L., syn. *C. macrosperma* Stokes, *C. lupulus* Scop.) shows that this recently rediscovered crop was originally cultivated in central Asia, India, and the Nile river valley. It was mentioned as a narcotic in Sanskrit documents at the beginning of 3000 BC. Later, hemp was described as a plant of healing and "joy" in the Sanskrit civilization, mostly as a result of religious celebrations where people became intoxicated from potions made of hemp leaves.

The first records of use in India date back to 2500 BC, and hemp was the first tow plant of the Chinese and Japanese. The Persians, who received hemp from the Punjabi in the upper Indies, used it exclusively as a narcotic. They. Iranians named it "bhanga," a term that meant "being drunk." Babylonians, Egyptians, and Phoenicians were probably not familiar with hemp, because no hemp remains were found in pharaon tombs or in the wrappings of Egyptian mummies.

Hemp gradually spread outward from central and southeastern Asia, especially as people migrated westward. Hemp was used by Indo-Persian tribes, who received it from old Arabia and the Caspian countries of Bactria and Sogdiana. Thracians produced hemp for tow and and passed the practice on to the Greek and Roman civilizations; hemp was also produced in Gaul. In the second part of Homer's *Odyssey*, written in the sixth century BC, boat equipment consisting of ropes and sails is mentioned. In part four, Jelena, wife of the emperor Telemachus, poured him and his companions "a miraculous juice sweetened with tranquilizers to help them forget their sorrow." Historians believe that these passages refer to hemp. Povolžje, in eastern

Figure 6.1 Hemp brewage.

Europe, was another important center of hemp production; there it was produced by Hungarian and Finnish tribes, and later by Bulgarians [1].

In records on the Spartans, King Hieron II. Syracose was said to have used hemp fibers and wood resin on his quest (287–212 BC). Herod's records from the fifth century BC state that Skits, the presumed ancestors of the Slavs, produced hemp that was similar to flax but much thicker and taller. Hemp is sown there but is also grows on its own. Thracians made canvas out of it that could not be distinguished from flex canvas. Jevtić [1] writes that narcotics were produced from hemp as far back as centuries BC. Botanists and historians believe that the Skits played a very important role in spreading hemp into Europe and Little Asia. In the first century BC, hemp used for fibers was mentioned by the Roman writers Lucius Julius Kolumela and Markus Terencius Varon; Plinius also mentioned hemp as a healing plant in the book *History of Nature*. He wrote that in fertile soil, hemp could reach the height of trees.

Between the second half of the first century to the early Middle Ages, hemp production experienced no noticeable developments. There are notes from the period of Karl the Great, however, mentioning hemp as a very useful plant. Similarly, the Russian Duke Oleg equipped a fleet of 200 ships on his march to Constantinople, an achievement that probably have been impossible without toughly sails made from hemp fibers.

By the beginning of the Middle Ages, hemp was commonly as a narcotic in the area of Arabian Caliphate, i.e., in northern Africa and part of Asia. Hemp's widespread use was often contributed to by the fact that the Koran prohibits drinking wine; the most available drug was hashish, which was often abused. It was not by chance that one of the Arabic tribes was known as the "Hashishians." The word "hashish" is an old Iranian word for "grass." According to other sources, an eighth-century Muslim sect of fanatical killers in Arabia were called "hasiasina," a name derived from the French and English words for "assassin."

When the Crusades ended, trade ceased between Russia and Tatar-Mongolia, which resulted in a reduction of hemp production for fibers. Around the same time, production began to spread in the western part of Europe. Cities like Venice and Genova reached the peak of their development, army fleets also strength, and hemp production quickly spread through Italy; Italy became a great hemp exporter. Growing economic power in Spain, England, and Holland allowed hemp production to spread to other European areas as well. The pressure of exporting competition began to cause problems, though, leading Pope Sikst V. to issue a written demand in 1856 setting quality standards for hemp fiber intended for export. As northeastern Russia recovered from the sixteenth-century Tatar-Mongolian, it once again began to produce and trade larger amounts of hemp. By the beginning of the seventeenth century, they produced enough for their needs and exported it to England and other countries [1*, 2].

The growth of hemp was first noted in America in the sixteenth century. The produced low-growing Scottish tall-type hemp in favorable growing conditions; this type of hemp differed from the southern types [3].

France was the most important hemp producer by the end of the eighteenth century, and by the early nineteenth century, it was being grown on 100,000 hectares of land. The introduction of steamboats and a reduction of hemp prices in Russia caused hemp production to drop overall in Europe. It was sown only in Italy and Hungary, and production fell across the continent. In ex-Yugoslavia, hemp was grown on 100,000 hectares of land in 1949; that number fell to less than 5000 hectares in 1991 and only 1000 hectares in 1998.

Throughout its history, hemp growth spread with nomadic tribes and nations. It served many purposes; in northern parts of Europe, it was used as a fiber plant, an oil plant, and a grain plant grown for nutrition. In Asia (China, northern India, Pakistan, Afghanistan, and Turkey), parts of Africa, and North and South America from the sixteenth century onward, hemp was produced mainly as a hallucinogenic drug and only rarely as medicine.

* Reprinted from Hemp – *Cannabis sativa* L, in *Posebno ratarstvo 2*, Jevtić, S., Jevtić, S., Ed., 200, Copyright (2006), with permission from Naučna knjiga.

Oil lobbies achieved the prohibition of hemp production in developed regions of America and Canada, due to propaganda that industrial hemp was associated with the use of illegal narcotics. In Europe, the female flowers *Cannabis sativa* L. var. *indica* were used for drug production only in the eighteenth century. The widepread production of this drug led the United Nations Organization (UNO) to hold a convention in 1961 for the purpose of fighting drug abuse. Consequently, depending on countries' varying laws, only cultivars with 0.20 to 0.35% THC (delta-9-tetrahidrokanabinol) may be produced. Since cultivation of fiber hemp has been permitted in some countries during recent decades, a number of surveys were published concentrating on the suitability of this plant for cultivation and industrial processing, and the interest in hemp byproducts is increasing. Hemp has been rediscovered as an interesting crop with a large plasticity, which allows it to be grown under a wide variety of agroecological conditions.

6.1.2 Botany and ecotypes

Hemp is an annual plant. It belongs to the family *Cannabaceae* and the genus *Cannabis,* with only one species of common (industrial) hemp *Cannabis sativa* L. Many botanists have conducted experiments in order to try and describe three species based on this monotype genus and polymorph species. Hemp (*Cannabis sativa*) is divided into two key types: European and East Asian. The European type is further divided into north Russian, central Russian, and southern types; the East Asian type is divided into Chinese, Japanese, and coastal subtypes. North Russian hemp is located in the extreme north and is therefore the earliest and least-branched type. Male plants ripen in 30 to 35 days, and female plants ripen in 60 to 80 days. Plants reach a height of 0.5 to 0.6 m and have small seeds with 12 to 15 g of 1000-seed weight.

Central Russian ecotypes are medium-early with a growing stage lasting between 110 and 115 days. Thin and branched stems reach a height between 1.3 and 2.0 m. Large leaves contain five to seven small leaves, and the 1000-seed weight is between 15 and 20 g. This type of hemp is very common.

The southern ecotype is also known as the Italian ecotype and ripens in 125 to 140 days. Plants grow to between 2.5 and 4.5 m high, and the 1000-seed weight is 18 to 26 g. Compared to other types, the southern type is considered more fertile due to the longer growing stage.

East Asian hemp has the longest growing stage, which lasts more than 140 days, and the plants reach a height of 4.0 to 6.0 m.

Differences among ecotypes are not so clear anymore, due to the presence of certain genetic structures in cultivars of individual breeders.

6.1.3 Plant morphology and anatomy of stalk

Growth and developmental morphological differences in hemp are caused by sexual dimorphism between male and female plants. Some new genotypes are also mutual.

Roots are well developed. The root system consists of a taproot with branched roots of second and third types. Taproot reaches a depth of 2.0 m, while lateral roots reach a depth of 0.6 m. The root system of female plants is usually more developed than the root system of male plants. The highest root mass can be found at a depth of 0.3 to 0.4 m, and the roots grow very intensively at the fast growth stage. The root weight is considerably lower than the weight of the aboveground part; this is the reason for lower yield when nutrient deficiencies or moisture exist. Hemp was formerly used as a test plant for uniformity of soil on test plots.

6.1.3.1 Stem

Plants can reach a height of between 0.5 and 5.0 m, depending on the basic ecotype and methods of crossbreeding; additionally, male plants grow higher than female plants. Stem diameter varies from 2 to 40 mm. Stem height and diameter depend on the ecotype, climate, fertilization, size of growing space, and other cultivation circumstances. The stem represents between 60 and 65% of the aboveground weight, and its length can increase 5 to 7 cm daily. Young stems are soft, juicy, and hairy, while old stems are firm and wooden. The stems contain fibers, where hemp is mostly grown. In mature plants, a layer of fiber sheaves is easily separated from the wooden part. Stem diameter can also vary on the same stem, according to the height at which it is measured. Near the ground, the stem is round, and the central part is hexagonal. In the middle of the stem height, furrows are visible that deepen toward the top. The stem is hollow throughout the length, except for the extreme ends, and it sometimes branches on the top (except in cases of high-density sowing). Variations in plant population may result in different branching and stem length, causing a variable quantity and quality of fibers. Stems consist of 5 to 20 internodes, and the internodes of male plants are longer than internodes of female plants. An increase in the number of internodes results in higher fiber quality.

The anatomy of stems (from the outer to the inner part) is as follows:

1. Outer stem layers consist of cover tissue. Cover tissue protects the plants from temperature shocks, mechanical damage, and excess transpiration, and plays an important role in gas exchange. Tissue consists of epidermis with one layer of tightly fitted cells, which are covered by cuticle. Constituents of cuticle are waterproof wax-like substances — cutin.
2. Primary crust consists of three tissues. Immediately below the cover tissue lies mechanical or supporting tissue called collenchymas, built of cells normally developed in all directions. At the edges of stem the collenchymas cells are joined in compact sheaves. These cells provide firmness to the stem, which is very important in the first development stages until the formation of fiber and lignifying of inner cells. Under the collenchymas is parenchyma, with thin cell wall and intercellular spacing. It has a diverse role of assimilating,

conducting, stocking, and so forth. Under the layer of parenchyma cells is starch endoderm, with one layer of starch grains. These reserve substances enable the plant to survive before the green plant part is ready to assimilate.

3. Primary fibers serve as a basis for yarn fibers. They consist of thin cellulose cell walls (pericycle parenchyma) and cells with thickened cell walls. Fibers are extremely elongated (prosenchymatous), which gives them firmness and more elasticity than wooden fibers. Primary fibers often join in sheaves. Parts of their cell walls can turn wooden with plant maturity.
4. Under primary fibers are phloem fibers and secondary fibers. A composition of sieve tubes, secondary fibers, and parenchyma cells exist. Sieve tubes of hemp can be depicted as capillaries with perforated barriers and cell walls that are neither thickened nor lignified. Sieve tubes are used for transporting organic substances in plants. Secondary fibers are similar to primary ones but their cell walls are thinner, less developed, and often appear in disorder. Sometimes they are located in compact or denser distributed concentric layers or sheaves. The secondary fibers are less firm than the primary ones. Primary and secondary fibers constitute rough wooden cells near soil and, in production, the bottom 5 to 10 cm are thrown away. The ratio of primary and secondary fibers is conditioned by variety and the technology of production. With high plant density, there are fewer secondary fibers, whereas with low plant density, the amount of secondary fibers increases up to four times. The smaller secondary fiber layer is a consequence of a delayed sowing date. Mediavilla et al. [4] and Schäfer and Honermeier [5] have shown that the formation of secondary fibers starts at the beginning of the flowering stage and thus fewer secondary fibers are formed, at a lower degree of ripeness.
5. Under schlerenchyma a thin layer of tender cells capable of division exist, called cambium. Toward the center of the stem, new wooden cells are formed; in the opposite direction, secondary fibers are formed. Tender cambium cells are a barrier for easy separation of stem bark and stem core. The fiber quality in the bark (mainly primary bast fibers and some secondary bast fibers) is much better than in the core (mainly high-lignin, libriform fibers). The appropriate bark:core ratio can be realized by aiming at high plant populations. The bast fiber content of the stem increases with plant population.
6. Under cambium there is a core part of cells and water vessels (xylem). Xylem consists of long capillaries with thickened and core cell walls that transport nutrients from soil. Core fibers that support the plant are mostly dead cells.
7. The inner stem part is often hollow and cannot be called pith in the real sense of the word. It consists of parenchyma cells, which can be dead or capable of division with young plants.

The morphology of the fiber cells of hemp can be significantly affected by weather conditions, location, and seed density. These same properties probably also affects the mechanical characteristics of hemp fibers [6].

Hemp leaves consists of petiole and blade. The first two leaves are simple and poorly developed, with jagged edges at the green cotyledons. The second pair of true leaves are triple-palmately lobed. The leaves that follow are grown from 4 to 9, or even 13, small parted leaflets. Central Russian types have 5 to 7 leaflets, while southern types have 9 to 11, or sometimes as many as 13, leaflets. The number of parted leaflets decreases toward the top of the plant. On the top, small to medium simple pointed and jagged leaves form. Leaves are hairy on both sides, and they are placed alternately only at the top part of the stem. The leaves' color can be intensely green to light green.

Flowers are self-pollinated and plants are dioecious, though monoecious varieties are gaining value throughout the world. Hemp is almost exclusively wind-pollinated. The flowering of female plants begins 2 to 3 days before the flowering of male plants; according to the ecotype, this difference can extend up to 10 days. Female plants flower after 15 to 30 days. The stage from fertilizations to full seed maturity lasts 40 days. From the opening of the first flowers to the flowering of all plants requires 5 to 10 days. The flowering stage produces a lot of pollen, with a couple hundred flowers opening daily on one plant. In cold weather, flowers remain closed, which causes poorer fertilization. Female flowers flower in the morning and are pollinated rather fast. Male plants (sometimes called white plants) mature prior to female plants (named black plants) following pollen formation.

The male flower consists of the pedicel, flower carpel, and stamen. Flower carpel consists of five elongated, inward-turning leaflets of pale green color. There are five stamens with long stamen filaments, so that anthers hang out of the flower.

The pistil of the female flower with superior ovary contains one seed, and the pistil has two parallel stigmas. It darkens 1.5 to 2 days after fertilization. Every female flower is surrounded by fine, hairy bracteole. The THC share with *Cannabis sativa* var. *indica* increases to the flowering stage and can be found in the highest quantities in bracts of female flowers.

With monoecious plants male inflorescence is placed together inflorescence on the top of the stem, and male flowers are joined in spikelet inflorescence in the nodes of leaves.

Fruit (we usually talk about seed regarding yield and harvest) is a two-part achene that is wide with a round shape. The calyx is quite hard and protects the seed mechanically. The seed is brownish-green, grayish, or silver grey to black in color, with more or less expressed mosaic spots. The 1000-seed weight varies according to ecotype from 12 to 20 g. The seed contains 30% of fat and 20% of protein.

Table 6.1 Definitions and Codes of Growth Stages of *Cannabis sativa* L. Plants According to Mediavilla et al. [26]

Code	Definition	Remarks
	Vegetative Stage	
1002	First leaf pair	
1004	Second leaf pair	
10nn	nn/second leaf pair	
	Flowering and Seed Formation	
200	GV point	Change of phyllotaxis on the main stem from opposite to alternate.
	Male	
2100	Flower formation	First closed staminate flowers.
2101	Beginning of flowering	First opened staminate flowers.
2103	End of flowering	95% of staminate flowers open or withered.
	Female	
2200	Flower formation	First pistillate flowers. Bracts with no styles.
2201	Beginning of flowering	Styles on first female flowers.
2202	Flowering	50% of bracts formed.
2203	Beginning of seed maturity	First seeds hard.
2204	Seed maturity	50% of seeds hard.
	Senescence	
3001	Leaf desiccation	Leaves dry.
3002	Stem desiccation	Leaves dropped.

Source: Reprinted from Mediavilla, V. et al., *J. of Int. Hemp Assoc.*, 5 (2), 67. Copyright (2006), with permission from International Hemp Association.

6.1.4 Ecology of growth and development

Growth and development of hemp can be roughly divided into the following stages: germination, seedling, slow growth, intensive growth (appearance of first flower buds), flowers and flowering, fruits, and maturity. New definitions and codes of growth stages are described in Table 6.1.

There are 9 stages characteristic of the organogenesis of generative organs for male plants and 12 stages for female plants.

The highest aboveground weight is created between the bud development stage and the end of the flowering of male plants. The male plants tend to flower and senesce earlier than the female plants. This means that growing conditions need to be highly suitable for quite a short period; this depends on plant ecotype or variety characteristics, however, because plants with a longer growing period create more aboveground weight. With early cultivars, the grain yield is higher. Plants with a longer growing stage are taller than plants with a short growing stage. When introducing new cultivars in different growing conditions, the amount of stem and fiber production often decreases, whereas seed yield increases.

The growing stage for breeding plants originating from eastern countries lasts between 140 and 160 days, andfort the temperature sum must be 3500°C. Northern ecotypes have growing stages from 60 to 90 days, and their temperature sum demand is from 800 to 1000°C. The earliness or lateness of French cultivars is expressed in numbers; for example, Ferimon 12, Fedora 19, Felina 34, Fedrina 74, Fibrimon 24, Fibrimon 56, and so forth. Higher numbers indicate that the cultivar is late. The growing period length is tightly correlated with the length of individual development stages. This is not true, however, for differences among ecotypes and cultivars from the emergence of seedlings to the appearance of three pairs of leaves. After the appearance of three pairs of leaves, male plants grow faster and develop more plant dry matter within a certain time unit. Intensive growth begins about 40 days after emergence, while additional growth of dry matter and fibers take place in the sixth decade. The length of the stage depends on the length of the growing period of the individual cultivar. Growth almost stops after flowering in male plants. With female plants, however, the growth of vegetative parts can be reduced due to poor nutrient provision at grain filling. In this case, their own spare resources are translocated into the seed.

Growth and development of hemp are conditioned by nutrient and moisture availability in soil, especially from weeks 4 to 10, when additional growing of dry plant matter is the highest. Hemp demands suitable climate and soil conditions. Infertile, sandy, cold, or too moist soil is inappropriate. Temperatures also greatly influence hemp growth. In 20°C, hemp can grow 4 cm day^{-1} but in 10.2°C, hemp can only grow 0.5 cm. In very favorable growing conditions (of moisture, temperature, and nutrients), hemp has been noted to grow as much as 12 cm per day^{-1}.

The minimal germination temperature is 4 to 5°C, although hemp will germinate between 1 and 2°C. The optimum laboratory germination temperature is 20°C. Changing temperature accelerates germination; young seedlings are not harmed by a sudden drop of temperature to –15°C.

Longer periods with subzero temperatures can destroy germinated seeds, especially with more than 80% field soil capacity for moisture. Emerged plants react differently to changes. Early sowing or cold climate areas can present an obstacle for germination. They can survive low periods of frost from –1 to –5°C. The crop already forms full ground cover after a thermal time of about 400 to 450°C. Spring temperatures can influence gender formation. Low temperatures from –5 or –6°C accelerate formation of monoecious plants with otherwise diecious plants; the number of monoecious plants in such populations can vary from 1 to 50%. At flower bud stage, we can differentiate gender of plants that are destroyed by subzero temperatures.

Sufficient moisture is the most important part of successful hemp growth in comparison to other crops; the shortage or excess of water during early growth stages can be a destructive factor for successful production.

Hemp behavior varies in different eco-regions, and the plants may not be able to make full use of the potential of the seasons all over the world. Ecotypes originating from eastern countries are long-day plants. They flower quite late and form only a few flowers. Northern ecotypes react to short days and consequently have lower dry matter formation. The cultivars grown in Europe have a critical photoperiod between 14 and 15.5 h.

6.1.5 Cultivation practice

The main problem facing hemp cultivation might be crop establishment: hemp is very sensitive to a lack of available nutrients from the soil, unequal or poor soil structure, and a shortage or excess of water during early growth stages.

6.1.5.1 Cultivars

Key cultivars in the EU assortment are as follows: Carmagnola, Delta Liosa, CS, Delta 405, Fedora 19, Fedrina 74, Felina 34, Ferimon, Fibranova, Fibrimon 24, Fibrimon 56, and Futura — standard 4/96. The cultivars Bialobreskie, Kompolti, USO 11, USO 13, YUSO 14, and YUSO 1 have less than 0.3% THC.

Under extremely dry and warm growth conditions, some cultivars — such as Secueni 1, Unico B, Kompolti Hybrid TC, and Beniko [8] — might contain up to 0.8% delta-9-tetrahydrocannabinol. In Australian growth conditions, the cultivars Kompolti, Unico B, and Futura 77 had a content of delta-9-tetrahydrocannabinol below the legal maximum of 0.35% (dry weight basis) [9].

Cultivars may be separated according to target production. Slovenian conditions for fiber (t), seed yield, and oil production (y) propose the following cultivars: Kompolti hibrid TC (y), Kompolti kender (t), Kompolti sazru (t, y), Novosadska konoplja (t), and Unico B (y).

Hemp has almost no limit demands with respect to crop rotation. It is usually sown after cereals, annual legumes, other arable field crops, and grass or cabbage. It is one of the plants that can often return to the same field; when fertilizing with stable manure, it can be grown as a monoculture. Hemp is a suitable precrop for cereals or can be sown after true cereals due to timely classical soil preparation. By introducing hemp into crop rotation, we can successfully suppress weeds in cereal crops, especially if crops are produced that allow for intensive reproduction and growth of weeds.

Results show that leaves contain 4.6 times more nitrogen, 3.2 times more phosphorus, and 1.7 times more potassium than stems. The average nutrient content in stems differs according to the stem part of hemp (Table 6.2).

The highest hemp demand for nutrients is noted in the first half of the growing stage. Root system weight at this stage is much lower than the aboveground part. Consequently, roots are not developed enough for nutrient uptake, which enables intensive growth and the available necessary nutrient amount in poor soil. In 100 kg of aboveground dry matter weight

Table 6.2 Average Nutrient Content in Individual Parts of Mature Hemp Stem [2, 4, 5]

	% in Dry Matter					
Plant Part	N	P	K	Mg	Ca	S
Leaf	2.40	0.42	1.77	0.59	0.81	0.45
Bark	0.57	0.22	1.06	0.30	0.32	0.35
Stem	0.52	0.13	1.06	0.12	0.32	0.36
Together	1.13	0.22	1.17	0.72	0.47	0.39

of hemp, various sources show the following nutrient amounts in the soil: 1.0–2.9 kg N, 0.22–0.75 kg P_2O_5, and 0.83–2.74 kg K_2O [4].

If we speculate on the basis of a published paper, the available nitrogen should be a minimum of 225 kg N ha^{-1} for 22,500 kg of aboveground matter ha^{-1} yield. Once analyzed, available nitrogen may exist solely for orientation purposes; however, in those cases, adequate input of organic nitrogen and potential mineralization are necessary.

Recommendations for seed production without soil analysis in Austria are the following: 100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, and 140 kg K_2O ha^{-1} for fiber production, the recommendations are: 80 kg N ha^{-1}, 80 kg phosphorus ha^{-1}, and 120 kg potassium ha^{-1}. In European regions, recommended nutrient amounts vary according to composition of soil and growing conditions, from 45 to 150 kg N ha^{-1}, 45 to 110 kg P_2O_5 ha^{-1}, and 45 to 110 kg K_2O ha^{-1}. The efficiency of the nitrogen fertilization rate depends also on available mineralized nitrogen, for the useful nitrogen rate depends on potential mineralization. If fertilization occurs with slurry or liquid manure, these fertilizers are clogged in the soil before sowing. Manure or compost can be plowed in autumn. In heavy or poor soil, we manure with phosphorus and potassium manures after basic soil cultivation in autumn, and part of them are used before or during sowing. With nitrogen, we manure before sowing or at the stage of three pairs of leaves, at the latest. Later additional fertilization — especially with high nitrogen amounts — negatively influences fiber quality or the height of plants, which can be too high for seed combining.

Autumn plowing is very suitable for hemp. Late spring sowing should cause the emergence of weeds, which are mechanically destroyed by presowing cultivation. Early spring is the appropriate time for sowing; later sowing is not recommended. Nevertheless, on the basis of experiments in Austria, the highest seed yield was achieved with sowing dates to the middle of springtime; later sowing did not result in maturing, even with early cultivars [12]. Sowing date trials with nine hemp cultivars were conducted across two seasons, incorporating dates between early and late spring sowing and a single autumn planting. Stem and bark yield declined with delays in sowing after the middle of spring in response to a decline in calendar days and thermal time from sowing to flowering. The response was most pronounced in sowings of Kompolti, which flowered within a short period and differed more substantially in durations to flowering [9].

Sowing depth is 2 to 4 cm or more in humus light soil. The energy of germination and germination force are described quite differently in literature on the subject. This depends on the 1000-seed weight, seed germination, and soil characteristics. In organic production, 8 to 15 kg seed ha^{-1} are recommended to be sown at 0.4 m interrow spacing, which enables interrow hoeing or cultivation. With low cultivars intended for oil plant production, the sowing of 13 kg seed ha^{-1} is recommended. In classical production, 12 to 20 kg seed ha^{-1} should be sown with interrow spacing of 22 cm in every other row. With high plants, the spacing should be between 0.5 and 0.7 m, and 12 kg seed ha^{-1} should be used. In such cases, it is best to cultivate every second or third line with double rows in-between. With short cultivars, 40 kg seed ha^{-1} should be sown.

In general, high plant populations without missing plants in the plant stands may give the best fiber quality. In high plant populations, the large plants suppress smaller ones, and this may even result in self-thinning. The influence of plant population on hemp yields was investigated in a few cases. In Australia, the investigated densities were from 50 to 300 plants m^{-2}. Plant density was most pronounced for populations of 200 and 300 plants m^{-2}, but the final harvest stem yield responded in a parabolic manner to plant density, with maximum yields at about 110 plants m^{-2} [9]. The stem yields and quality depend on inter-plant competition influenced by dense plant population [13], especially at 270 plants m^2, and high nitrogen rate [14] causes self-thinning. Depending on growth conditions, differences in the percentage of the long, high quality bark fiber at final harvest were generally small and not significant [9].

Weed management is not a problem with hemp, because hemp suppresses weeds efficiently as one of the most weed-competitive plants. Hemp production for oil with longer interrow spacing enables the germination and development of some absolute weeds (*Cirsium arvense* L., *Sorghum halepense* L.) and some relative weeds.

6.1.6 Harvesting, storage, and processing

The official suggested harvest time for fibers is 2 to 3 weeks after flowering. Based on the results of the physical properties of the bark, Keller et al. [15] also concluded that the optimal harvest time is at the beginning of seed maturity, which is approximately 3 to 4 weeks after male flowering; in spite of that, the maximum yield of the stem, bark, and fiber was reached at male flowering ("technical maturity") [4].

Special machines are used for harvesting, and these machines should be bought by producers joined together in an association. Dry stems or barks with lengths of 0.5 to 0.7 m can be cut by using an adjusted machine otherwise used for flax. Dry plant material is packed, according to contractor demands, in bales or bundles.

The average yield of stem dry matter in agriculture practice varies between 2000 and 5000 kg ha^{-1}, sometimes reaching even higher. In field micro trials, the yield can reach 12,000 kg ha^{-1}. Higher yield in trials is almost always a consequence of experimental errors due to a lack of consideration of edge influence or too-small plots [11; Starevi, personal communication and author experience]. But according to Struik et al. [16], conventional grown fiber hemp may yield up to 22,500 kg aboveground dry matter per hectare (20,000 kg stem dry matter ha^{1}), which may contain as much as 12,000 kg ha^{-1} of cellulose, depending on environmental conditions and agronomy. Some of the same cultivars used in previous experiments (Kompolti, Unico B, and Futura 77) had the highest single-plot dry stem yields in Australian trials (up to 15,000 kg ha^{-1} and bark proportions up to 40%) [8].

Hemp harvesting for bird food and oil is executed at the stage of full maturity when the seed can be shaken from the top of the plant. Combines may be used for harvesting.

Machines need to be adjusted for high cultivars. For grain, only the top of the plant can be harvested; the rest can be harvested for fiber. Seed yield in Austria in 1995 and 1996 amounted to between 800 and 1300 kg ha^{-1}, while yields in Belgium and France in some cases exceeded 2700 kg seed ha^{-1}.

Hemp seed is dried after harvesting to 10% of dry matter, and the drying temperature must be less than 50°C. Seed used for the cold-pressing of edible oil should not contain any crop protection substances and fungi contamination. It is stored and sold in paper or jute bags.

6.1.7 Utilization: special organic products

Hemp is valued for its rough, firm, and water-resistant fibers; it is used in the rope industry to make fish nets, different fabrics, and tents. Fibers are also useful in the paper industry, as a construction material, as fuel, and more. The core part is used for making artificial fibers, cartons, and construction material. During recent decades, a very extensive description of hemp utilization for industry processing and marketing was done, providing for its use in textiles and geotextiles [17–19], high-quality papers [20, 21], composites for the automotive industry [22, 23], and as insulation materials for houses [24, 25]. The versatility of the seed lends itself to the development of numerous products for the food, cosmetic, therapeutic [26], beverage, and nutraceutical industries. The quality of oil is currently under investigation in order to improve the economic and/or environmental performance of an unconventional crop through innovative uses of its components and byproducts. As a result of the processing of hemp fibers, the seed becomes an interesting byproduct [27].

Organically produced and processed products deserve special attention. Hemp may be utilized for biotextile insulation and as building blocks for biohouses; as an energy crop for heating; and as edible seeds and oil, in beverages and cosmetics, and so forth. The highly polyunsaturated oil of hemp seed has been used for printer's ink, wood preservatives, and detergents and soaps [28].

In the case of using bast fibers of flax and hemp for insulation, it is essential to follow good manufacturing practices and to keep the insulations in a dry place throughout the manufacturing and building process in order to minimize hygienic risks (fungi and bacteria) in insulations [29].

Technical fibers are of different quality. The fiber of the male flower plant is soft and strong and can be compared to flax fiber for making canvas. Female plants have rougher fiber, suitable for making ropes. The fiber morphology and chemistry are influenced by the growth stage, the age of the plant, and fiber processing. The fibers of green hemp are soft and thin, with mechanical properties similar to flax fibers. Lengths of primary and secondary fibers also differ. Primary fibers are 8 to 40 mm long, while secondary fibers are no longer than 4 mm. Primary fibers are joined in sheaves, which represent technical fibers after splitting from other tissues. The lengths of technical fibers vary from 0.2 to 0.5 m or more, according to stem length. The highest yield from technical fibers comes from the middle and top plant part. Yield can be between 15 and 30%, though 20% is difficult to exceed (male plants are the exception).

The amount and quality of technical fibers are conditioned by stem quality: longer stems result in longer fibers and better yield. Thinner branch axles are to be expected among higher plant populations. This is an advantage in fiber production because hemp fibers are phloem fibers, which are located directly beneath the epidermis**.** In thinner stems, they can be separated more easily and are much more suitable for the textile industry [30]. This condition may also be reached by dense plant populations, which cause strong elongation of the primary bast, producing long low-lignin fibers. Branched stems negatively influence fiber quality and yield; yield is lower with thick stems.

Firmness and color also depend on time of harvest and method of after-treatment. A promising method for obtaining fine hemp fibers is the controlled biological degumming of decorticated bark in bioreactors using adapted microorganisms and their enzymes [31]. Kelle and Leupin [15] considered the mechanical decortication of green dry stems without degumming of the bark; the results revealed that a harvest time at the beginning of seed maturity leads to easier decortication without any effect on the tensile strength of the bast. For decortication of fresh stems, including a subsequent degumming process, a harvest after the flowering of the male plants results in fiber losses during decortication and fibers of reduced fineness. Hemp fibers may be dirty yellow, green-grey, metal grey, or almost white in color.

In order to revive the use of hemp in the textile industry, new technical and technological solutions are necessary [32]. Special attention has been given lately to the growth of hemp, which is much quicker than forest increment. While pine forest increments produce 2.5 m^3 ha^{-1}, 10 to 12 m^3 of wood from a hecare of hemp are produced in comparison. Around 65% of hemp stem weight consists of wood, which is constituted of 40 to 48% cellulose, 26% lignin, and 32% pentosans. Its caloric value is no less than 15.74 MJ kg^{-1}, which is more than is found in wood (11.30 MJ kg^{-1}) and less than coal (20.09 MJ kg^{-1}). The wooden part of hemp has good thermoinsulation properties in construction and potential in the chemical industry for furfural synthesis. Hemp has been receiving a lot of attention as a possible fuel and construction material from environmentalists and organic producers. Ashes from wooden hemp parts should also be mentioned, due to the content of 24% CaO, 4,85% P_2O_5, and 6,3% K_2O.

6.1.7.1 Hemp seed

As reported by Callaway [33], hemp seeds have not been studied extensively for their nutritional potential in recent years, nor has hempseed been utilized to any great extent by the industrial processes and food markets that have developed during the twentieth century. Hemp seed contains 20 to 30% carbohydrates, 25 to 35% oil, 10 to 15% insoluble fiber, and a rich array of minerals [33–35] and vitamin E [36]. Hemp seed also contains 20 to 25% proteins, mainly edestin and albumin. Both of these high-quality storage proteins are easily digested and contain nutritionally significant amounts of all essential amino acids. In addition, hemp seed has exceptionally high levels of the amino acid arginine [33].

Hemp seed can be used for poultry feed and is also appreciated as food for birds. After oil pressing, 65% of the oil seed cake weight remains from seed. Approximatelt 1 kg of oil seed cake can replace 4.5 kg of corn silage from whole plants. Oil seed cakes are high-quality protein feed because 1 kg contains as many digestible proteins as 2.85 kg of oats, 3.0 kg of barley, 3.2 kg of corn grain, or even 25.3 kg of corn silage from whole plants.

Hemp seed can be used for making "hemp" bread in a mixture made with 15% hemp share. Besides seed and fiber production, hemp can also be produced for fuel. For these purposes, only cultivars without THC content or with the allowed THC content are produced. For production and marketing, only cultivars with less than 0.3% THC may be used.

Hemp seed, in addition to its nutritional value, has been used to treat various disorders for thousands of years in traditional oriental medicine. It has demonstrated positive health benefits, including the lowering of cholesterol and high blood pressure [37]. Recent clinical trials have identified hemp seed oil as a functional food, and animal feeding studies demonstrate the long-standing utility of hemp seed as an important food resource [33].

The oil, because of this feature and the presence of linolenic acid, is ideal as an ingredient for light body oils and lipid-enriched creams, known for their high penetration into the skin [28].

Hemp oil's iodine value is from 140 to 167, with an average of 159. With mechanical cold-oil pressing, we get 28% of oil. Refined hemp oil is ranked among quality oils on the basis of its color and taste. Most often, it is used for the preserving of fish and in flour confectionery industries. As an easy-drying oil with unsaturated fatty acids, it can be used in the production of soap, varnish, and oil colors. Oil can be used for nutrition, and the production of edible hemp oil is unlimited in Europe. Cold-pressed oil tastes like grass juice, making it suitable for culinary purposes. The price of hemp oil is somewhere between olive and sesame oil.

Hemp seed oil has been deemed perfectly balanced for human nutrition in regard to being a rich source of two essential polyunsaturated fatty acids: linoleic acid (18:2 omega-6) and alpha-linolenic acid (18:3 omega-3). The omega-6 to omega-3 ratio (n6/n3) in hemp seed oil is normally between 2:1 and 3:1, which is considered to be optimal for human health [33]. In addition, the biological metabolites of the two essential fatty acids, gamma-linolenic acid (18:3 omega-6; GLA) and stearic acid (18:4 omega-3; SDA), are also present in hemp seed oil.

The industrial processing of edible oil has also begun. An increase in the use of hemp oil for salad dressings has been noted, and microwave heating has recently been found to be particularly effective in releasing membrane-bound tocotrienol and tocotrienol-like compounds and in maximizing the stabilization of biological materials against degrading enzymes [38]. Microwave treatment of hemp seed produces positive beneficial changes in the quality of hemp oil. The elevated tocopherol concentration suggests an improvement in hemp seed oil quality that can become an economically and environmentally sound resource for the functional food and nutraceutical industries [27].

6.2 Flax

6.2.1 Introduction

Flax (*Linum usitatissimum* L.) is one of the oldest cultivated plants known to mankind. It was grown in Neolithic times in Switzerland and southern Germany, and in Spain during the Bronze Age. Egyptians grew it in 3000–4000 BC and were followed by the Romans, Gauls, and Celts, who were the beginners of production in western Europe; Slavic nations took over production from the Greeks.

The ancestor of flax was pale flax (*Linum angustifolium* L.). The primary center of fiber flax is southeastern Asia and for oil (seed) flax is northern Africa. A lot of fiber flax is produced in Northern Europe at the Atlantic coast (The Netherlands, England, Belgium), at the North Sea (Denmark, Sweden), and in the Baltic States. Moderately cold and moist climates suit flax well. Oil (seed) flax grows better in the dry and warm climates of Southern Europe, Africa, India, Argentina, and so forth, though Russia produces 65 to 70% of yield worldwide. The largest importer of flax grain is Great Britain [39].

Flax production has emerged as a potentially interesting undertaking in a wide range of agroecological environments, also as an efficient plant for remediation heavy metals from the soil. There are several advantages that could result from flax being produced organically, as well for textile and edible seeds.

6.2.2 Botany and cultivars

Flax belongs to the family of *Linaceae*. Of 200 species, the most important for production is the Eurasian subspecies of ordinary (cultured) flax *Linum usitatissimum* L. According to the branching, stem height, and so forth, flax is divided into fiber flax (*Linum elongatum*), oil (seed) flax (*Linum brevimulticaulis*), and intermediate flax (*Linum intermedium*) [39].

Flax varieties suitable for Slovenian conditions are not officially verified, in most cases. Cultivars of fiber flax are Belinka, Natasja, and Regina. From the Netherlands come the very-well-known cultivars Wiera (the oldest one), Diana, Noblesse, and Solido, which are suitable for spring sowing. The French early cultivars of oil flax are Antares, Mikael, Ocean, Linda, Atlante, and the winter cultivar Nivale. The German early cultivars are Ceres, Hella, Kreola, and Liflora. There are also Ariane, Barbara, Blue Cip, Hungarian Gold, Ran, Kiszombori 41, Linneta, Gregor, Norlin, Omega, Sandra szegedi 41, and Sandra szegedi 62.

Lisson and Mendham [40] reported that European flax cultivars yielded significantly more stem and bark fiber than the Australian flax cultivars. Of the former group, Ariane (841 g m^{-2}) and Marina (883 g m^{-2}) performed the best in terms of stem yield production, while Viking had comparable bark yields to these two cultivars.

6.2.3 Morphology

Flax has poorly developed spindle-shaped roots, which reach a depth of 15 to 30 cm. There is a system of lateral roots on the taproot.

Flax stem is straight at the first growth stage and bended with winter plants. The height of the stem from cotyledon to the branching point is 0.5 to 0.8 m. Stems are round, 1 to 2 mm thick, with a waxy surface (Figure 6.2). Its special green color has a cabbage gloss of dark green to light yellow; lighter shades are desired.

The inflorescence of flax is the top part of the stem where side branches appear; this part ranges from 5 to 15 cm in length. Fiber flax is less branched than oil flax, which is in correlation with production purposes. There are 50 to 255 fibers in the stem of fiber flax, while. individual flax fibers are represented by phloem also called bast. Between 30 and 50 fibers are glued into sheaves by pectin. Pith in the middle of the stem dries with maturing and leaves a hole in the stem that is smaller toward the top.

Leaves are sitting, free, alternating, and more or less pointed on top with a slightly waxy surface. The leaf blade is narrow and elongated, with three parallel veins that distinguish it from other dicots.

Flowers are placed on top of stems and side branches. They consist of five petals, five sepals, five stamina, and a pistil. Flax is a self-pollinated species, and the self-pollination ratio is 95 to 98%. Petals are colored and can be white, pink, or blue-violet.

Figure 6.2 Flax.

The fruit of the flax is a capsule with five segments, each containing two seeds. The flax seed is smooth, chocolate-brown to bright yellow in color, with significant shine. Seeds of some cultivars are yellow or olive green; they are flat, oval; and pointed at one end. The seed is relatively large: 1000-seed weight of fiber flax is 3.4 to 5.4 g, oil (seed) flax is 5.4 to 14 g, and combined flax is 6 to 8 g. The weight of a hectoliter is 65 to 75 kg hl^{-1}.

6.2.4 Growth and development stages

Flax development stages are as follows: germination, emergence (cotyledon), first pair of true leaves unfolded, third pair of true leaves unfolded (start of leaf spiral), intensive growth (stem extension), bud formation, flowering, and maturing. The intensive growth stage takes between 10 and 16 days. At this stage, daily growth reaches 3.8 cm. Flowering begins 41 to 56 days after emergence and lasts about 1 month, the duration being longest in the earliest emerging crop. The final harvest is carried out once the plants lose all green color. The growth period of spring-sown hemp is 75 (90) to 110 (120) days.

Growing flax for seed demands 100 to 300 m of space isolation, or the plant will be unable to crossbreed.

The stages of flax ripening are as follows: green maturity, early yellow maturity, yellow maturity, and full maturity. During the green maturity stage, the crop seems green although the bottom third of the stem is dry. The grain is still in milky condition.

Early yellow maturity is known for waxy maturity. It bends under the pressure of fingers and gives the impression of wax. Most of the plant is yellow green at this point. Yellow maturity takes place 5 to 7 days after early yellow maturity. Leaves on the bottom half of the stem begin to fall off, and the upper leaves fade. Flax capsules are yellow and partly dark; the grain is hard with a normal light-reddish color.

In full maturity, the capsules and stems darken. Most of the leaves fall off, and the. stems lose their elasticity and become lignified. At this stage, the flax is over-mature.

6.2.4.1 Growth conditions

Fiber flax is usually produced as an early variety and oil (seed) flax as a winter variety. Fiber flax flourishes in moderately warm climates where emergence temperatures are optimally between 2 and 5°C) and growth temperatures do not exceed 16 to 17°C. It grows best in moderate to cool conditions, particularly during seed filling, and is thus essentially a crop for temperate regions, because high temperatures and temperature fluctuation at the capsule and flowering stages reduce the number of seeds per capsule, seed weight, oil yield, and quality.

The oil (seed) flax requires higher temperatures than fiber flax and does not tolerate extreme changes in temperature. Young plants of early flax can survive up to –4°C and of winter flax up to –12°C.

Fiber flax belongs to hygrophytic plants with high transpiration coefficients between 400 and 780, or even as high as 1000. Negative drought influence on plants is the strongest from the emergence to the flowering stage. Rainfall or irrigation late in the season can result in a flush of new tillers and leaves, causing uneven ripening [41]. Suitable soil moisture is 70% to feul field soil moisture content. Optimal relative air moisture is between 60 and 70%. Oil (seed) flax also has lower water demands.

The environmental factors most likely to be responsible for yield reductions are high temperature, which causes significant yield losses due to its effect on hastening development rate, and the consequent shortening of the growing cycle and water deficits. The possibility of extending the length of the growing period through earlier sowings seems, however, limited by the difficulties caused by low temperatures in the emergence phase [42].

An opinion on modest light was not confirmed in research because a lack of light reduces photosynthesis and causes lodging. Short intensive growth from the bud formation stage to the flowering stage (50% of nutrient demands in this period) and weak pumping power of flax roots demand favorable nutrient provision. Soil must be airy but, nevertheless, sandy soils and heavy clay are not suitable.

6.2.4.2 Cultivation practice

6.2.4.2.1 Crop rotation. Crop rotation is necessary in flax production. It may be sown on the same field only every 5 to 6 years, according to our own experience, though literature on the subject recommends 6 to 11 years between rotations, mostly due to root system diseases. In crop rotation, flax can be sown with all field crops; it is only important that soil be weed free.

Flax growth can be reduced by the allelopathic influence of grasses *Lolium perenne* L. and *Phleum pratense* L, and the consequence of allelopathy is reduced carbohydrate synthesis.

6.2.4.2.2 Soil. Soil for flax production must have a good drainage system: lighter sandy soil to clay soil with a pH between 5 and 7 is suitable. Direct calcification before sowing reduces fiber quality. Very fertile sandy soil is not suitable for flax production even with optimal water supply, because it causes excess stem elongation.

The recommended soil cultivation is a classical one with plowing, harrowing, or presowing machines. Basic presowing soil cultivation for early flax is performed in the usual way for early crops, and for oil flax the same as for winter crops. Due to poor root development, plowing should be performed to full depth. In shallow soil, the sowing layer can be extended to the depth of 20 to 25 cm some years before. Tight soil is loosened. It is important to create exactly the right field surface with presowing cultivation; the sowing layer must have the right structure.

6.2.4.2.3 Fertilization. Due to poor nutrient uptake, nutrients must be available throughout the entire growing period. The highest demand for nitrogen is noted between the leaf spiral and flower capsule stages; the highest demand for phosphorus between emergence and the leaf spiral stage; and the highest demand for potassium between the first three weeks of growth and the flower bud stage.

In 100 kg of dry matter yield and the corresponding grain amount, between 0 and 1.4 kg N, 0.4 and 0.5 kg P, and 1.1 and 1.6 kg K are found. Between 5000 to 6000 kg stem dry matter and 1000 to 1500 kg seed ha^{-1} can be produced. Combined production reduces seed yield 20 to 30%. In 100 kg of seed, 4 kg N, 1.8 kg P, and 1.15 kg K are found in the soil.

Flax is thus a crop with low nitrogen requirements [43], reducing the risk of nitrate surpluses in groundwater. Fertilization should not be conducted directly with organic fertilizers but only in precrop, in the amount of 20 t of stable manure ha^{-1}. The necessary calcification of previous crops should also be conducted.

Special attention is given to nitrogen use. A high content of mineral nitrogen exists in the soil, and abundant fertilization with nitrogen fertilizers can result in lodging, excessive branching, low technological stem yield, and poor yield quality. Winter flax is fertilized in autumn with up to one-third of the joint nitrogen rate, and early flax with one-half of the rate. All phosphorus, potassium, and other nutrients should be added to the soil in presowing.

6.2.4.3 Sowing and cultivation practice

Flax grain must have at least 95% germination, a natural shine, and should not be damaged; when rubbed, it should turn fat and purity should be 99%. It should not contain any dodder (*Cuscuta villosa* L.) or ryegrass (*Lolium* spp.) impurities or seeds of cultivars produced for other purposes, such as seeds of oil flax in fiber flax. When oil flax and fiber flax plants cross, the yield quality changes. It cases like this, it is best to buy variety seeds.

Early flax is sown at the same time as early cereals, and winter flax is sown at the end of summer. In Australia, where growth conditions allow autumn sowings, the flax gave higher yields of both stem and seed compared with winter and spring sowings [40].

Flax is sown with the sowing machine for cereals. Fiber flax is sown at the usual interrow spacing of 10 to 12 cm (also 6 cm), oil flax is sown at 20 to 45 cm spacing, and combined cultivars are sown at 15 to 20 cm interrow spacing. The recommended sowing rate of fiber flax is unusually high: 2000 to 3000 seeds m^{-2}. Because up to 40% of fiber flax seeds usually fail, the sowing amount of fiber flax is 140 to 150 kg seed ha^{-1}. Oil (seed) flax is sown at a lower density; 70 to 80 kg ha^{-1} suffice with the goal of obtaining at least 400, or perhaps between 600 and 700, plants m^{-2}. For combined cultivars, 100 to 120 kg ha^{-1} seeds may be needed. In trials, Diepenbrock et al. [41] and Casa et al. [42] found that yield was unaffected by seed rates varying from 200 to 800 seeds m^2 in the lowest — as well as the highest — yielding locations. In the other locations, low and high seed rates yielded less than the intermediate rates of 400 and 600 seeds m^2 [42]. However, an optimum seeding rate depends on the sowing date, the target production of seed or fiber, the soil quality, and weather conditions, and it involves a compromise between maximizing yield and minimizing potential losses from lodging. In some growing conditions, the crop was able to compensate for reduced stand densities mainly by increasing the number of capsules per plant [44].

The sowing depth should be between 1.5 and 2.0 cm; only occasionally should sowing take place up to 3.0 cm deep in light and dry soil. Crop provision begins by rolling after sowing. In case of crust formation, harrow should be performed, but not after emergence. Flax can be hoed after emergence, at 14-day intervals, when sowing in wide rows.

Organic nitrogen fertilizers are used for additional fertilization of early cultivars one time, three weeks after emergence; this occurs twice for winter cultivars: at the height of 10 cm and at the flowering stage.

In dry conditions, the crop is irrigated. One measure of water should not exceed 30 mm.

6.2.5 Harvesting

Fiber flax is harvested at the stage of early yellow maturity, and oil flax at the stage of yellow maturity, the same as combined flax. Seed flax does not require any specialized farm machinery, as sowing and combine harvesting can be carried out with the same equipment as that used for winter cereals. Harvesting of fiber flax can reduce yield due to stubble remains; fiber flax is ready for harvesting when two-thirds of stems are yellow and leaves fall off, which happens a month after the opening of the first flowers. If plants are harvested manually, they can be grabbed without weeds, pulled out, and shaken. They are sorted according to length into three groups: longer than 67.5 cm, 60 to 67.5 cm, and shorter than 60 cm.

Dried plants are put in stacks. Stacks are made of tied sheaves with 15 cm diameter or of untied plants. Heaps are dried for 10 days or until they are completely dry. Dried flax is tied into bigger sheaves, 30 to 40 cm in diameter Special combines are used for pulling out flax. Stems are processed as soon as possible or are stored in extremely dry places.

Oil flax can be harvested by cereal combine, though the plants must be completely dry. Where production allows the use of chemical substances, desiccation is performed when 5% of capsules are still green, and combining is done after a week. Combining speed should not exceed 2 km h^{-1}. Ware seed is dried at a temperature of 80°C, and moisture in storage facilities should not exceed 10%; the recommended moisture is between 8 and 10%.

Fiber flax yield can reach between 2500 and 6000 kg ha^{-1}. Grain yield usually varies between 220 and 2820 kg ha^{-1}; Lisson and Mendham [40] reported that the flax grain yields in trials were between 1560 and 2180 kg ha^{-1}. The highest yield of winter crop recorded in the U.S. was 4390 kg grain ha^{-1}. Expected yields usually fall between 1000 and 1500 kg grain ha^{-1}; combined fiber-grain production achieves yields somewhere in-between.

6.2.6 Utilization

Flax fiber represents raw material for textiles (linen and blends with cotton and other fibers) [45]. Flax fiber is suitable for the most beautiful canvasses of the highest quality, such as damasts. Flax fibers are also used for making clothes, underwear, and laces, and as composites, paper [45], and for insulation materials.

Natural flax fiber is a good replacement for glass fiber in automotive parts [46]. The advantages of natural fibers include their lower density, sound absorbance, lower shatter properties than glass, and lower energy costs for producing composites.

The revival of traditional flax canvas production for tourists is another interesting development, and the production of oil flax seed has its own marketing advantages as a delicious supplement for bread and cakes.

All bast fiber plants, including flax, must undergo the process of retting to separate the fiber from the woody cells, which are called "shives" and constitute the major trash component of flax fibers. The retting starts with the dew of dry steams, where decomposition is affected by usual microorganisms or can be focused on enzyme-retting [47, 48] or frost-retting fiber straws in damp air in Finland [49], because the retting process and drying, decomposed nonfiber components must be integrated with the subsequent mechanical processing steps to clean the fiber for specific applications. However, good quality and long fibers could provide a low-cost source of material for diverse applications if harvested and processed without specialized equipment [50, 51]. Short bast fibers are used as insulation and in packaging materials [52]. Shive has been used as a component of packaging materials, but its main use is still as fuel. The properties of raw materials should be studied to enable selection of the right material for appropriate technical applications.

Output efficiency is very important in flax fibers. Stephens [53] reported total fiber yields of straw ranging from 20 to 30% in a series of flax varieties, where the majority of the nonfiber components are shives.

Oils dry very fast and are consequently used for the production of paints, lacquer, linoleum, varnish, ink for printing, herbicides, and many other pharmaceutical or cosmetical products. Flax oil in combination with fiber is a very reliable plumbing seal. It is also used as an additive in baking. Ground seed and oil seed cakes are an important source of nutrition for animals. Flax seed is also gaining its popularity as an additive to breads and cereals. Approximately 100 g of seed contains 6.3 to 6.6% moisture, 18.0 to 20.3% protein, 34.0 to 37.1% fat, 33.6 to 37.2% carbohydrates, 4.8 to 8.8% fiber, 2.4 to 4.5% ash, 170 to 271 mg Ca, 2.7 to 43.8 mg Fe, 0 to 30 μg β-carotene, 0.17 mg thiamine, 0.16 g riboflavin, and 1.4 mg niacin. Raw flax oil contains 0.25% phosphatides, and the content of fatty acids is as follows: 11% palmitic, 11% stearic, 4% hexadecanoic, 34% oleic, 20% linoleic, 17% linolenic, and 3% unsaturated $C_{20\text{-}22}$. Amino acids in the seeds are found in the following quantities (g $16g^{-1}$ N): 8.4–10.3 g arginine, 1.5–2.5 g histidine, 2.5–4.55 g lysine, 0.7–1.5 g tryptophan, 5.6 g phenylalanine, 7.50 phenylalanine + tyrosine, 2.3 g methionine, 6.09 g methionine + cystine, 4.37–5.1 g threonine, 6.54–7.0 leucine, 4.0–4.54 isoleucine, and 5.46–7.0 g valine [54, 55]. Ash contains 30.6% K_20, 2.1% Na_2O, 8.1% CaO, 14.3% MgO, 1.1% Fe_2O_3, 41.5% P_2O_5, 2.3% SO_3, 0.2% Cl, and 1.2% Si [54].

Flax is a crop that most strongly (compared with cotton and hemp) absorbs and accumulates heavy metals from the soil, suitable for growing in industrially polluted regions. It removes considerable quantities of heavy metals from the soil with its root system and can be used as a potential crop for cleaning the soil from heavy metals [56].

Many positive properties are attributed to flax in folk medicine. It has been used as a laxative and a substance with diuretic, calming, healing, soothing, and anticancer properties. The anticancer substances also contain 3′-dimethylpodophyllotoxin, podophyllotoxin, and β-sitosterol. It is supposed to help with bronchitis, conjunctivitis, and diarrhea. Furthermore, dietary flax seed supplementation could prevent hypercholesterolemia-related heart attacks and strokes [57].

Ground seed is an appreciated compress in folk medicine. It is used also in combination with white mustard and lobelia.

6.3 Jerusalem artichoke

6.3.1 Introduction and crop description

Jerusalem artichoke (*Helianthus tuberosus* L.; syn.: *H. mollissimus* E. Wats) is a C-3 warm-season crop native to the southern part of North America. It is a member of the family *Asteraceae* and a close-related crop to sunflower (*Helianthus annuus*). In the past, it was used as food for Indians, and in Europe, it was first grown in France. Today it is grown throughout the world, and its utilization has increased slowly over time. The yield is a good nutritional source for diabetics, processing biogas [58], ethanol [59], fructose [59, 60], and substitutes for artificial sweeteners, e.g., inulin [60, 61]. The crop is suitable for organic production, especially due to its well-expressed weed competition and low production inputs.

Jerusalem artichoke forms numerous roots. It is grown mainly for tubers, whose place of formation is underground, where the main root prolongs to the stem. Thickened tubers resemble potato tubers, only their eyes are knotty. Their color depends on variety and includes red, violet, white, ochre, and similar hues.

The aboveground parts of the plants start growing and developing after spring frost, and they join rows in the middle of June. Intensive stem growth takes place between July and the autumn months (depending on the cultivar). The thickening of tubers begins after stems and leaves are fully developed and should continue in winter; therefore, the green parts are not cut until then. The plant can reach a height of 1.5 to 3 m above ground, and stems turn wooden at the flowering stage. The inflorescence diameter is between 5 and 7.5 cm. Late cultivars flower in October and do not produce seeds in continental climate.

The main part of the Jerusalem artichoke used for human consumption is the tuber. It contains about 80% water, and the dry matter (= 100%) contains between 10 and 15% proteins and 75 to 67% extract containing approximately 60% inulin, 1% fat, 4 to 6% fiber, and approximately 5% ash. According to Mullin et al. [62], the Jerusalem artichoke contains 20 to 25% protein on a dry basis and up to 43% dietary fiber. The phosphorus content is around 0.099%, Ca is 0.023%, Fe is 3.4 g 100 g^{-1}, and there are some trace elements, such as Al, Cl, I, Mg, K, S, and Zn. The tubers contain a small amount of vitamins B and C, purine-based arginine, histidine, and other compounds like betaine, choline, and hemagglutinins [63].

6.3.2 Growth requirements and organic cultivation

Jerusalem artichoke is a particularly interesting and suitable crop for low-requirement environments [64,65]. In spite of some assumptions that the plant is insensitive to dry conditions, its acclimation to water stress strongly reduces growth in the early growth period and aboveground biomass, and marginally modified the fructan's accumulation to the final harvest [66]. It also grows well in humid soil and favors heat as well as colder temperatures. In-soil tubers can resist temperatures as low as –30°C, while aboveground parts cannot survive the frost. The Jerusalem artichoke cannot be grown in very humid soil with poor draining properties. Neutral soil is optimal, but it can also grow in soils where other crops cannot. The variation width for different cultivars is between 4.5 and 8.2 pH.

The Jerusalem artichoke is a prime candidate for organic cultivation. There is no special requirement for crop rotation — the previous crop can include clover, grasses, and clover-grass mixtures. However, grower attention must be focused on soil pests like *Agreotes* sp. and rodent animals, because they can destroy the yield of tubers that will then be unmarketable; the tubers may be completely eaten by an extensive rodent population. The plant can be planted as a fallow crop and grown continuously for 4 to 5 years on the same field. After that, because small tubers remain in the field, weeds can become inconvenient. For this reason, the following crop rotation must include plants for animal feed, which require frequent cutting. It helps to exhaust Jerusalem artichoke, so that the field can be used as a normal arable field. However, the rotation of Jerusalem artichoke like a fallow crop planted before and after grasses, clovers, or its mixtures for 4 to 5 years is suggested.

Most of the culticars, which are extremely varied, originated in Switzerland and France [67]. The cultivars may be separated into two groups: early maturing (such as Grando) and late maturing, such as Kharkov, Miello, Dub, Rico [68], Violet de Rennes, Bianco, and so forth.

Only high yield cultivars are acceptable for wider production with appropriate shape and color. In the U.S., bacteria-resistant cultivars have been created with higher frost tolerance on the green parts, higher pH tolerance, photoperiodic tolerance, and more.

The soil can be previously cultivated, as with potato planting. If necessary, calcification is performed in autumn. At basic plowing, 30 (40) t ha^{-1} of stable manure should be added; it can be replaced by green manure, the plowing of grass-clover mixtures, and so forth. In such cases, green manure or harvest remains can be fertilized with liquid manure. In general, the Jerusalem artichoke does not require a lot of fertilizing; its needs range from 15 to 30 kg ha^{-1} of nitrogen, 40 to 50 kg of phosphorus, and 40 to 60 kg of potassium ha^{-1} per year. After presowing field preparation, Jerusalem artichoke can be planted early in spring or even in autumn.

The suggested growth area is 60×40 cm for tuber production and 60×30 cm — or even 30×30 cm — for green plant mass production. Tubers are

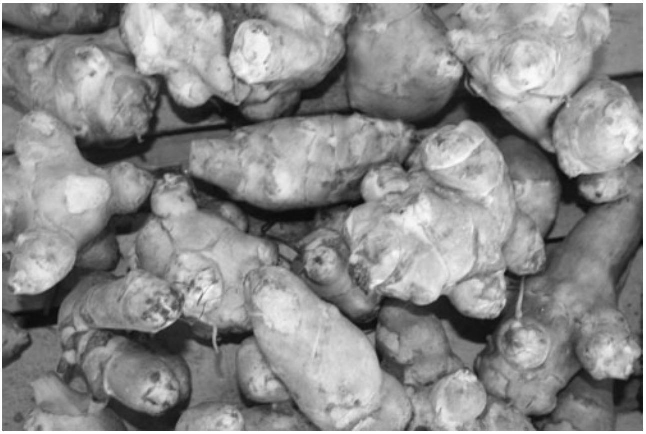

Figure 6.3 Tubers of Jerusalem artichoke.

planted at a depth of 6 to 10 cm, if seeding depth from the soil top to the tuber is taken into consideration. The quantity of seeding material depends on the tuber size and varies from 1200 to 2000 kg ha^{-1}.

During the first year, Jerusalem artichoke is hoed in interrow spacing in mid-spring, when it is shed before covering the rows with aboveground mass. As soon as the soil is covered, weed control is no longer necessary due to intensive overgrowth. In the second and following years, tubers are removed from interrow spacing for easier hoeing the following year. The more extensive approach allows crops to be harrowed only in spring and hoed once more if necessary. Yield is conditioned by soil characteristics and fertilizing. In favorable conditions and appropriate crop provisions, a yield similar to the potato can be achieved; the average yield is between 15 and 30 t of tubers per hectare.

Jerusalem artichoke tubers (Figure 6.3) are not picked for supply but according to the possibility of sale. The best storage place is in soil, except for storage facilities with high humidity (over 80%) and low temperatures between 0 and 5°C.

6.3.3 *The perspective of the use of Jerusalem artichoke also produced as organic product*

Jerusalem artichoke has been an important source of food for the human diet, and it also has medical and industrial applications [69, 70]. It is a recommended food for patients with diabetes, because tubers contain no starch but do contain approximately 15% of inulin. In folk medicine, it was used as a diuretic and aphrodisiac, as well as for stomach problems and other effects. It has been grown to produce fructans that can be used for many purposes, like ethanol production [71, 72] and vinegar.

Jerusalem artichoke is one of the most important candidates for use as a raw material for the industrial production of biological fructose and inulin. Its naturalness makes it more attractive to consumers than synthetic products. The yield of stalks and tubers at flowering time produces a yielding potential of total sugars (fructose + glucose) and inulin from 10.4 to 18.6 and 8.0 to 17.9 t ha^{-1}, respectively [73]. Jerusalem artichoke in inulin applications could be used for diagnostic use (inulin with a high degree of polymerization, over 20) and for improving the consistency of cakes and other bakery products (inulin with a smaller degree of polymerization, 6–10) [74]. Fructans can be used in the food industry and in several other industrial and medical applications [66].

Jerusalem artichoke is a welcome feed for organically kept pigs and also a good aboveground mass for the production of snails. It can be grown on an additional open field close to the pigsty, so that the pigs can consume fresh living tubers and young plants. The aboveground biomass is also used as fresh feed or silage (two to three hay harvests per year).

Lignified plants may be used as fibers for natural building materials. When producing for silage, between 30 and 50 t ha^{-1} can be produced, creating a silage mass with a similar starch-protein ratio (1:10) to corn silage. The crop can be cut two to three times in summer and late autumn before frost. When done this way, tuber yield is reduced by half, but higher-quality green fodder is produced.

The plant can also be utilized for biogas production, especially on farms without animals. Anaerobic digestion experiments showed that fresh and ensiled aboveground parts of the plant could produce 480 to 680 liters biogas kg^{-1} organic material [58].

6.4 Sweet potato

6.4.1 Introduction

Sweet potato, also called batate and ipomea (*Ipomoea batatas* [L.] Lam., Poir., syn.: *Convolvolus tuberosus* Vell., *Batatas edulis* Choisy), originates from Central America; from there, its use spread to other areas and continents. It reached Europe in the same way as beans, potatoes, and corn after Columbus's discovery of America. Sweet potato was carried to Spain for the first time in 1492. The ancestry of the sweet potato is not known due to the inability to gather such information on wild-growing plants. It is a perennial crop but can be produced as annual crop. Although an unknown plant in some temperate climates, it is an important food source in tropical areas. Throughout the world, sweet potato is produced on more than 9 million hectares of land at a total weight of 140 million tons and with an average yield 15,000 kg ha^{-1}. The highest amounts are produced in China, the U.S., New Zealand, and Australia; within Europe, it is produced in Italy, Spain, and Portugal across approximately 6000 hectares [75].

6.4.2 Botany

Sweet potato belongs to the *Ipomoea* genus and *Convolvulaceae* family. There are many cultivars known in the world, but only in Papua New Guinea do more than 2000 exist (Ivančič, personal communication). The cultivars are produced from vegetative reproduction of selected plants that are a result of natural and artificial crossing. A small number of cultivars are mutated. Sweet potato is a cross-pollinated plant with a strong autoincompatible system, but perfectly autoincompatible genotypes also exist that can be easily self-pollinated.

Seedlings have branching root systems. Adventitious roots appear quickly on the nodes of climbing stems so that the stem is rooted as it grows. Tubers are a result of the secondary thickening of some adventitious roots under the soil surface. When tubers ripen, stems are removed and tubers dug out. Tuber color may be white, yellow, violet, or pink, and they weigh between 0.5 and 2 kg, or even as much as 7 kg with some cultivars (Figure 6.4).

The stem is annual and reaches between 1 and 5 m in length. Stems are partially straight, trailing, or partially trailing. Stem diameter is between 3 and 10 mm, and the internodes are 2 to 10 cm long. Th surface can be smooth or hairy, and the color of the stem is green to purple with occasional violet spots on ground internodes.

Leaves vary according to genotype and age; they are simple and alternating. The first true leaf is usually small, smooth or hairy, cordate, with a pointed or obtuse top. Other leaves are usually larger, measuring 5 to 15 × 5 to 15 cm. Petioles are from 4 to 30 cm long. The leaf surface can be wavy

Figure 6.4 Tuber of sweet potato.

or straight, with two nectar glands at the bottom, and its shape can be whole or palmately lobed. The color is green or violet with occasional violet spots at the bottom. Leaf veins are palmate and possess the same color scheme,

Flowers grow individually from nodes or as inflorescence. A flower consists of five sepals (between 1.0 to 1.5 cm long), five grown petals (funnel-shaped, 2.5 to 5 cm long and 2.5 to 4.5 cm wide), five anthers (grown at the bottom of petals with uneven lengths; filaments are white with gland hair), and a pistil (joined with ovary, with an orange nectar gland). The flower contains two bracts, and petals are white, pink, or violet pink. They open between 9:00 a.m. and 11:00 a.m. in the morning and remain opened in cold or cloudy weather for an even longer time. The fruit is a dark and round pod, usually containing one to two seeds. The seeds are dark and irregularly shape, 3.0 to 4.5 mm long with hard teguments.

6.4.2.1 Climatic characteristics, growth, and development

Favorable growing conditions for the sweet potato exist between the geographical coordinates 40°N to 32°S. Successful growth and development are conditioned by 4- to 6-month periods without frost.

The growing stage of the sweet potato lasts between 3 and 12 months, depending on cultivar and climate. Cultivars with longer growing stages than corn (150 to 160 days) should not be chosen in certain areas; in central Slovenia, for example, the growing stage of early cultivars is 4 months. With sweet potatoes, talk is about cuttings and not about seedlings. The main problem with seedlings is their initial slow growth. Emerged plants are ruined by temperature from 0 to 2°C; even developed leaves are not resistant to this temperature but developed stems can survive –2 to –3°C, depending on the development stage, variety characteristics, and soil. Tubers freeze at –2 to –3°C, and soil moisture is important. Tubers most often freeze in sandy soil at lower temperatures than in heavy soil.

In tropical climate, the sweet potato is a perennial plant; in moderate climates, it can be grown as an annual plant. This is the result of temperature demands, because plants stop assimilating at temperatures lower than 10°C. For successful growth and development, temperatures higher than 20°C are required — the optimal temperature is between 30 and 35°C.

The sweet potato plant is cross-pollinated, i.e., insect-pollinated. It rarely flowers in moderate climates, due to longer day lengths; rather, the sweet potato is a short-day plant. Most cultivars will flower in 10- to 11-hour day lengths or 12- to 14-hour night lengths. The plant forms partial flowers at 12-hour day lengths, and flowering stops at 13.5-hour days.

6.4.3 Cultivation practice

Sweet potato is less demanding than the common potato (*Solanum tuberosum*). Organically produced sweet potato can be included in all crop rotations but stable manure with precrop is recommended. Stable manure or compost are useful, or even obligatory, in cases of low nutritional requirements and badly structured soils.

It can be produced in heavy clay soil but also grows in sandy soil. In heavy soil, tubers are elongated with crust and less durable; light soil with an appropriate water and air regime is best, and garden or humus soils are not recommended. In such soils, either the primarily vegetative part is developed or thick tubers are not resistant to storage. Basic cultivation is done to the plowing depth. Presowing cultivation and seeding take place when night temperatures go above 10°C. The seeding bed is prepared in the classical way or seeding hills are used. In tropical areas, sweet potato is sown in heaps or high hills because successful growth and development demand airy soil.

The needs for available nutrients before planting sweet potato are as follows: 60 kg N, 90 kg P_2O_5, and 90 kg K_2O ha^{-1}. The needs for nutrients are higher in the second part of the growing stage. The data regarding nitrogen needs are contradictory, because its surpluses can affect intensive growth of green vegetative mass instead of tubers. Tuber yield goes up with increasing potassium application, but differences exist among varying genotypes [76, 77]. The cultivar maturity group of the sweet potato should also play an important part in nitrogen fertilization recommendations [76, 78]. Hansen [79] and Srikumar and Ockerman [80] found few differences in the chemical composition and "quality" of potatoes subjected to organic or conventional cropping practices. In the field trials, four elements in potato tubers (P, Mg, Na, Mn) and four elements in potato leaves (N, Mg, Fe, B) were influenced by fertilization treatments, while extractable P, Ca, Mg, and Cu were higher in organically fertilized potato plots [81].

Yano and Takaki [82] concluded that the mycorrhizal colonization can influence growth promotion at soil pH 4.2 (twofold increase in whole plant dry weight), but not at pH 5.2. As a result, no significant difference was detected in whole plant dry weight between the mycorrhizal plants at pH 4.2 and nonmycorrhizal plants at pH 5.2. The mycorrhizal plants at pH 4.2 showed reduced toxic symptoms of Mn (brown specks on mature leaves) and Al (poor root growth) compared to nonmycorrhizal ones, but tissue concentrations of P, K, and Ca did not increase in mycorrhizal plants.

The crop is cultivated by hoeing on three to four occasions. Cultivation in the tropics comprises only minimal cultivation right after planting. In West India and the western U.S., occasional cultivation prevents the rooting of trailing stems and consequently the formation of a higher number of small tubers. When soil moisture is below 60% of water capacity, the crop is irrigated.

Sweet potato is harvested when leaves start to turn yellow; this does not apply to continental areas, however, because leaves will remain green until frost due to high moisture and low temperatures. The best technological ripeness indicator is the cut tuber: if it does not turn black when exposed to sun and dries in a half-hour, it is ripe. Unripe tubers secrete sticky, milky white juice. Prior to picking, the aboveground mass may be removed. Mowing is practically impossible, though checking the possibility of aboveground mass silage is advisable. Tubers can be removed with potato harvesting machines or plows, and they should be left to drybefore picking. After harvesting, tubers are storied at 10°C with 75% relative air moisture. Storage taking place 2 to 3 weeks after harvest results in a 10 to 15% loss of tuber weight. Changes in carotene concentration during storage have also been noted [83, 84].

6.4.4 Plant reproduction

Reproduction is described in various ways in literature on the subject. According to some sources, plants can be reproduced with seeds or by vegetative means with whole tubers, tuber parts, cuttings, rooted parts of the vine, and tissue cultures. Seed reproduction is used for breeding purposes; for planting at home, small whole or cut tubers and approximately 20-cm-long shoots can be used instead. For wider reproduction, 25- to 40-cm-long cuttings taken from stems, with no roots, may be used.

The plant develops new roots from nodes only when in contact with soil; rooted cuttings can also be grown in protected areas. For 1 hectare, 400 to 500 kg of tubers are needed, from which shoots should be removed and planted for the purpose of developing roots. Plants are ready for planting in 6 weeks, when they will have grown five to six leaves and developed roots. It is simpler to use cuttings taken from stems for this purpose; these are planted in prepared crests in spacings of 70 (100) × 40 (50–100) cm by machine or hand. Sowing material should be sown in soil at two-thirds length. If shoots are used, roots should not dry out. Planting in cloudy weather is most desirable, or the roots should be soaked in a liquid mixture of cattle mud and soil in covered areas.

For simpler production in temperate climates, tubers should be planted in heated, well-protected areas, so that stems reach a length of three m before cutting and planting occurs. Stems are cut into parts with two internodes and planted in crests in light soil. Rooted shoot are rarely used for planting larger areas.

6.4.5 Nutritional value and food processing

The quality of sweet tubers varies among cultivars (Figure 6.5). Tubers contain 69 (70)% water, 0.75 (0.2)% fat, 1.8 (3–6)% protein, 26.1% starch and sugar, 1.3% cellulose, and 1.1% ash. The caloric value of 1 kg of tubers is 5154 J. Starch value varies from 10 to 32%, while sugar content reaches 6%. Sweet potatoes grown in the tropics contain more sugar.

In some places, sweet potato is a basic food source, such as bread or potatoes; there are many possibilities for its use. As a vegetable it can be cooked, baked, or roasted. It is also used in sugar, alcohol, and beer production. Sweet potato may be canned and used as food. It is a well-known ingredient in the confectionary industry, and its flour is added when making bread [75]. Sweet potato flour is mainly prepared by drying the peeled slices

Figure 6.5 Tasting of different sweet potato cultivars.

in a hot air drier, or by drum drying cooked sweet potato mash into flakes, followed by milling and sieving [85]. In addition to the possibility of utilizing sweet potato in wheat-based baked foods, dried and ground sweet potato flour has been investigated as a potential supplement to noodles, puddings, gruel, and so forth [86–89]. Research into the pasting behavior of sweet potato flour obtained by different drying techniques, and the structural properties of its starch, showed that the clustering of starch granules and reduction in their crystallinity as a result of processing decided the properties of sweet potato flour and its suitability to food product development. Sweet potato flour with a low viscosity profile produced by hot-air drying processes is useful in the development of calorie-rich specialty foods and food formulations for children in which a higher solid content per unit volume is required [90]. However, knowledge about changes in carbohydrates during cooking, baking, and the heat moisture treatment of sweet potato [91–94] is essential to determining suitability of sweet potato flour for new requirements, as in snacks, soups, sauces, and more.

6.4.6 Health value

The intake of taro, sweet potato, and potato was associated with a decreased risk of kidney cancer death [95]. Anthocyanins from purple sweet potato have antioxidative activity. Results from studies suggest that the antioxidant activity of sweet potato differs depending on plant part and cultivar [96]. However, anthocyanins from purple sweet potato showed stronger 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging activity than anthocyanins from red cabbage, grape skin, elderberry, or purple corn, and eight major components of the anthocyanins from PSP showed higher levels of activity than ascorbic acid [97].

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