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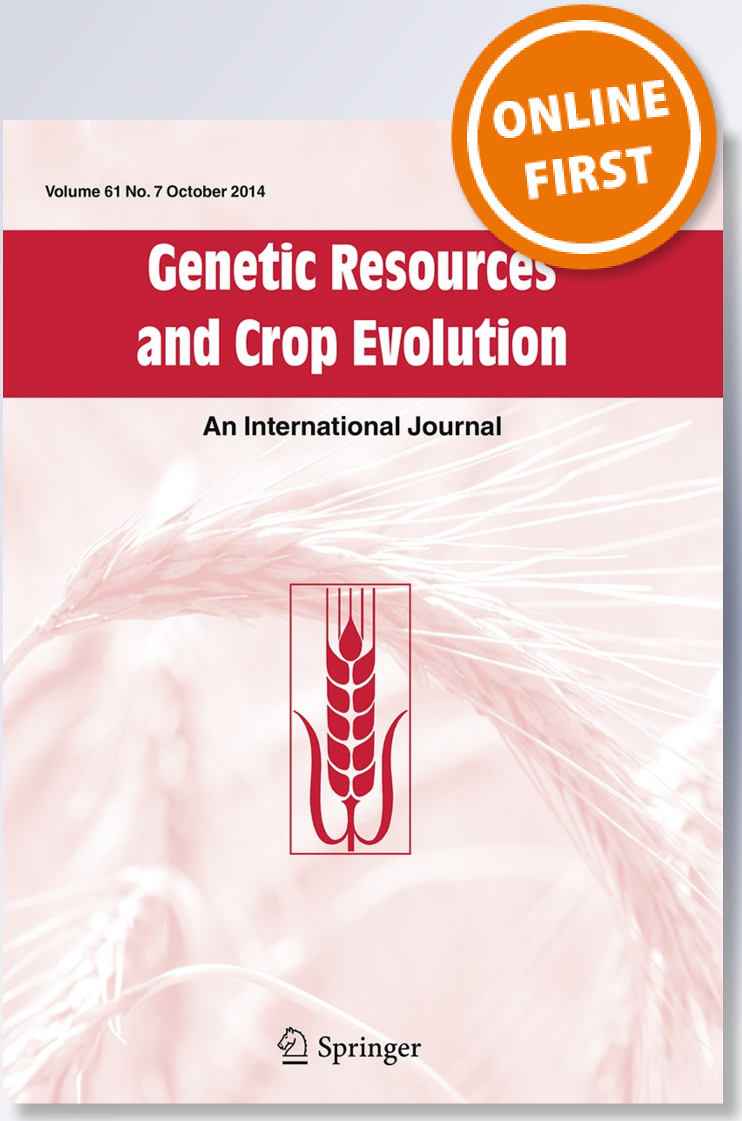

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RESEARCH ARTICLE

A domestication assessment of the big five plant families

Karl Hammer · Korous Khoshbakht

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Abstract To assess domestication levels in the five big families of higher plants (Compositae, Leguminosae, Orchidaceae, Rubiaceae, Gramineae) we propose an index that categorizes taxa according to the strength of domestication. The selection of species followed the Mansfeld approach, i.e. all plants cultivated by man with the exception of ornamentals have been included. The basis for our studies was Mansfeld's Encyclopedia (Hanelt and IPK in Mansfeld's encyclopedia of agricultural and horticultural crops, vol 1. Springer, Berlin, p 6, 2001). Information about additional cultivated species has been collected in the past years. Altogether 2,166 cultivated species have been analyzed—1.013 Leguminosae (5.2 %), 735 Gramineae (7.6 %), 293 Compositae (1.2 %), 84 Rubiaceae (0.7 %) and 41 Orchidaceae (0.2 %) (in brackets the percentages of cultivated species within the respective families). The domestication assessment confirmed the importance for man of the families with relative high numbers of highly domesticated (H), domesticated (D) and semi-domesticated (S) species for Gramineae and Leguminosae, followed by Compositae, and relative low levels for Rubiaceae and Orchidaceae. The assessment data of Compositae, Leguminosae and Gramineae are mainly shown for H (because of the great number of species), for Rubiaceae and Orchidaceae they are provided in total, including all assessment categories. Selected species from the different families are discussed within their commodity groups. The reasons for the differences between the families are analyzed. Factors causing high levels of domestication assessment are high species diversity, global geographic distribution, good seed storability, good seed quality characters (starch and oil) and the earlier co-evolution of plants and animals (rodents) towards seed/fruit sizes and qualities. Leguminosae can make use of the nitrogen from the air with the help of *Rhizobium* bacteria. Gramineae can effectively use the available nitrogen. This has led to combined suitabilities for domestication and agricultural developments. The paucity of domesticated species is dependent on high specialisation, a high level of secondary defense compounds and the lack of carbohydrates digestible for man. Diverse cultural and genetic factors can have positive or negative effects on use preferences by man.

Keywords Compositae · Domestication · Gramineae · Leguminosae · Orchidaceae · Rubiaceae · Trait analysis

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Introduction

Only in the last 50–60 years science is beginning to get an idea about the wealth of plant species supporting mankind. Mansfeld's Encyclopedia (Hanelt and IPK 2001) could reach a certain conclusion but it is still necessary to continue and complete these studies using all possibilities for obtaining new information especially in the light of fastly progressing genetic erosion (Hammer and Teklu 2008; Khoshbakht and Hammer 2010). The further development of Mansfeld's account is certainly a necessary agenda.

Five plant families contain more than 10,000 species each and, thus, can be considered as the most successful groups within the higher plants with respect to species diversity, namely Compositae, Orchidaceae, Rubiaceae, Leguminosae and Gramineae; nevertheless, there are considerable differences in the usefulness for man of the families. In a preliminary account Khoshbakht and Hammer (2008a) considered the number of cultivated species according to the Mansfeld approach (Hanelt and IPK 2001) and found large differences in the percentages of crop plants within the families. As the number of crop plants and species diversity in general are positively correlated among the Higher plants ($r = +0.56$, Khoshbakht and Hammer 2008b), the differences between the families require a detailed comparison.

It is not only interesting to interpret why plant families contain crop plants or came otherwise into economic focus of man, but trait assessments can help to understand patterns of domestication and predict and explore the domestication potential of various floras. Dempewolf et al. (2008) have presented a family-wide relevant study of the Compositae. Our approach is intended to obtain information about all five big plant families which comprise about 35 % of the species within the higher plants (Khoshbakht and Hammer 2008b).

Materials and methods

Our present elaboration is based on Mansfeld's Encyclopedia (http://mansfeld.ipk-gatersleben.de/). A consultation of this important monograph is always advisable. A concise synonymy is given together with use and plant parts used, references of literature (especially for cases with crop plants not yet listed in Mansfeld's Encyclopedia, in this case the citation of the source is indicated). Hanelt and IPK (2001) provided the basic data for the cultivated species according to the Mansfeld approach (Pistrick 2003). The historical account of the development of the Mansfeld approach is presented by Hammer and Khoshbakht (in prep.).

The work with checklists provided strong input for the latest edition of Mansfeld's account (Hanelt and IPK 2001) and is continued until recently (Oman—Hammer et al. 2009; China, Yunnan—Li et al. 2011). The data obtained from this work are used to complete the present account.

Some further important sources for newly reported species are provided in the following. A series on "Promoting the conservation and use of underutilized and neglected crops" was developed, comprising now more than 20 volumes, stressing the value of minor and rare crops and thus contributing to information about species richness in crop plants (Hammer et al. 2001). A byproduct of this activity was the initiation of a series of articles for the journal Genetic Resources and Crop Evolution (Springer, Dordrecht) under the general headline: "Notes on neglected and underutilized crops". A number of species of crop plants has been newly found and described supplementing the general account of crop plants (e.g. Feyissa et al. 2007; Gladis and Pistrick 2011; Ram et al. 2007). Stimulated by the biodiversity approach, a number of other publications appeared giving account of whole areas or groups of crop plants (e.g. Abraham et al. 2008; Dansi et al. 2008; Gebauer et al. 2007; Nayar 2011; Pandey et al. 2008). They all provided new information for our present account. A wealth of new information has been obtained from the large projects Plant Resources of South-East Asia—PROSEA (Lemmens and Bunyapraphatsara 2003) and the ongoing Plant Resources of Tropical Africa—PROTA.

The importance of the cultivated plants is elaborated. The different use types, given in the tables for each family, are presented in the following way: Food (seeds, fruits, roots, vegetables, beverage), food additives (flavouring, spice, colouring), animal food, medicines, material (tanning, dyestaff, fibres), environmental, others (social-stimulant, pesticide, honey, poison, fuel). These items are similar to the commodity groups which are proposed by Westphal and Jansen (1989).

Our calculations are principally based on 7,000 species, the so-called Mansfeld approach. Newly reported crops, after the appearance of Hanelt and IPK (2001), are included together with relevant literature for the Orchidaceae and Rubiaceae. For the other big families with a high number of cultivated species (Compositae, Leguminosae, and Gramineae) the relevant tables concentrate mainly on the highly domesticated crops (H) because of space limits. The full data are reported by Hammer and Khoshbakht (in prep.).

There have been several attempts to evaluate the degree of domestication in plants (see e.g. Zeder et al. 2006; Fuller 2007; Purugganan and Fuller 2009).

Dempewolf et al. (2008) assigned species with a '+' or '−' indicator for the presence or absence, respectively of an indicator. The summed domestication indicators reaching from 0 to 1 (no/weak) are indicative of weak or no domestication, indicators of 2–3 (semi) for semi-domestication and indicators of 4–5 (strong) for marked domestication. This classification was used in our treatment in a slightly modified way, trying to give a more detailed evaluation by providing the factors A–E (see below) with evaluation figures from 0 to 4 each. Thus 0 indicates no domestication (N), 1–3 weak domestication (W), 4–6 semi-domestication (S), 6–9 domestication (D) and >9 high domestication (H).

According to Dempewolf et al. (2008) the following five categories are differentiated:

A = Phenotypic differentiation, attempting to present the level of phenotypic differentiation between the domesticate and its wild progenitor,
B = Extent of cultivation, a combination of extensiveness and geographical distribution was envisaged,
C = History of cultivation, reaching from recently taken into cultivation = 0, to relatively young crop, cultivated since <100 years = 1, traditional crop plants >100 <500 years = 2, old crop plants >500 <2,500 years = 3, very old crop plants >2,500 years = 4. This classification follows in principle Hammer and Laghetti (2006), as chosen for Italy. The world-wide approach was responsible for minor adaptations,
D = Major genetic alterations, major genetic shifts or interspecific hybridization occurred in the history of the cultivated species (nothomorphs),
E = Improvement through breeding, known breeding efforts since the beginning of scientific plant breeding.

As there may be different domestication levels within the same crop in most of the categories, depending on geographical, economic and other factors, always the highest estimated mark was given.

The sum of indicators for each crop was determined, within the Compositae e.g., *Lactuca sativa* could reach the highest number of 20 and *Helianthus annuus* obtained an evaluation of 14, mainly because of its later domestication. Both belong into the category "highly domesticated", reaching from >9 to 20.

Results and discussion

From the domestication assessment a deeper insight in human selection for cultivation in the plant kingdom can be expected. The big plant families are handled in the order of their species diversity.

Compositae Giseke

The Compositae are today considered as the largest family of flowering plants, at least in terms of named species (Anderberg et al. 2007) and approximately 10 % of the flowering plant species belong to this family. They have a cosmopolitical distribution and are only absent from the Antarctic mainland. They are quite common in Europe, Africa, America and Australia, in woodland, grassland and bushy ecosystems, but play no major role in tropical rain forests.

The most important crops are contained in the tribes Lactuceae (*Lactuca*) and Heliantheae (*Helianthus*). Other important crops, as mentioned by Simpson (2009), are *Cynara*, *Carthamus* (Cardueae), *Tanacetum* (Anthemideae) and *Cichorium* (Lactuceae). The highly domesticated species of this family are presented in Table 1.

Table 1 needs special explanations. After the botanical names of the selected species with few infraspecific taxa in alphabetic order (mostly after Hanelt and IPK 2001) with additions, as indicated (see the following tables), follows a column: Uses type (parts used). This column is similar to the checklist approach (Hammer 1991). The abbreviations give a certain impression about the use of the taxa. More data about distribution, evolution and use can be obtained from Hanelt and IPK (2001). The next column contains Domestication indicators developed after Dempewolf et al. (2008).

There are only relatively few highly domesticated crop plants in the Compositae. But the number of

Table 1 Highly domesticated taxa (H) of Compositae

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Carthamus tinctorius L.	M.; Oi. (fr.); Fo.; D. (fl.)	2	2	4	1	2	11	H
Cynara scolymus L.	M., Ve. (fl.)	2	3	2	2	2	11	H
Cynara cardunculus L.	M., Ve. (l.)	2	3	2	2	2	11	H
Dahlia × *pinnata* Cav.	M. (r.); Fd.; Or.; Ve. (r., l.)	3	2	3	2	0	10	H
Helianthus annuus L.	Or.; Fo.; Oi. (s.); Ve.; Sp.	2	4	2	3	3	14	H
Helianthus tuberosus L.	Ve (r.); Fo. (r.); Ve. (r.); Or., He.	2	2	3	2	1	10	H
Lactuca sativa L.	Ve. (l., st.). Oi. (fr.)	4	4	4	4	4	20	H

[a] D.: Dye plant; Fo.: Fodder crops; M.: Medicinal; Oi.: Oil crops; Or.: Ornamental; Ve.: Vegetable; He. : Hedge plant; Fd.: Food and Food additive

[b] (fl.): Flowers; (fr.): Fruits; (l.): Leaves; (r.): Roots, rhizomes; (st.): Stem; (s.): Seeds

[c] A: Phenotypic differentiation; B: Extent of cultivation; C: History of cultivation; D: Major genetic alterations; E: Improvement through breeding

[d] H: Highly domesticated >9; D: Domesticated 7–9; S: Semi domesticated 4–6; W: Weakly domesticated 1–3; N: Not domesticated 0

crop species with lower levels of domestication assessment is considerable (see Hammer and Khoshbakht, in prep.). Nearly all commodity groups could be found within the material studied, only crops for fibers are rare within the Compositae (e.g. *Xanthium*). A few examples are given in the following, the assessment figures are provided in brackets after the species (taken from Hammer and Khoshbakht, in prep.).

Food

Compositae are lacking the typical storing carbohydrates, such as starch and, thus, have not been in the selection focus of early agriculturists. But Compositae have seeds and fruits rich in oils of high nutritional value. To the most important oilseeds of this family belong *H. annuus* (H 14), *Carthamus tinctorius* L. (H 10) and *Guizotia abyssinica* (L.f.) Cass. (S 5) (Important for the local agriculture of Ethiopia and a promosing oil crop—Dempewolf et al. 2010a, b) with oil contents in the fruits of 50, 48 and 43 %, respectively. The oil content can be improved by breeding. Original material of the sunflower has an oil content of only about 30 %. Other crops with high oil contents include *Iva annua* L. var. *macrocarpa* (Blake) R.C. Jackson (W 3), *Madia sativa* Molina (S 5) and *L. sativa* (H 20). As a rule, the fruits have also high protein content: *Helianthus*—20 %, *Carthamus*—30 %, *Guizotia*—22 %, *Madia*—20 % and *Xanthium strumarium* L. (W 2)—46 %.

There are root crops with highly nutritional compounds, often used as vegetables, as *Scorzonera hispanica* L. (D 7) and *Tragopogon porrifolius* L. (S 5) from the old world and *Helianthus tuberosus* (H 10) and *Smallanthus sonchifolius* (Poeppig. et Endl.) H. Robins. (D 7) (Hermann and Heller 1997) from the New World.

The number of vegetables which are grown for the use of their leaves and shoots is very high in the family, with *L. sativa* being the most important one. Similar vegetables are *Crepidiastrum sonchifolium* (Maxim.) Pak et Kawano (W 1), *Cynara cardunculus* (H 11), *Glebionis coronaria* (L.) Spach (S 5), *Crepidiastrum denticulatum* (Houtt.) Pak et Kawano (N 0), *Pterocypsela indica* (L.) C. Shih (D 8). An impressive amount of leaf vegetables from the family are used, especially in tropical areas and East Asia.

Flowering shoots and even flowers constitute a certain part of the vegetable diet. The highly domesticated *Cynara scolymus* (H 11) from the Mediterranean area is an impressive example. Artichokes are today grown on more than 120,000 ha worldwide. Another crop from the family in which the immature inflorecenses are consumed as a vegetable are the so-called “Puntarelle”, richly ramificated, fleshy inflorescenses of *Cichorium intybus* (H 11) which have been selected in Italy and are going to become a success in many parts of the world today.

Beverages

There are many of such uses within the family. Chamomile (*Matricaria chamomilla* L., D 9) and other species are used for tea, *C. scolymus* goes into a typical aperitif from Sicily (cynar), the bitter roots of *C. intybus* serve as a surrogate for coffein-free coffee. A liqueur is made from *Artemisia absinthium* L. (W 3)—Absinthe.

Food additives

There are many species of the Compositae used as spices and condiments. *Artemisia dracunculus* L. (S 4) is traded internationally for flavouring vinegar and in perfumery. Several species of the genus *Artemisia* are grown as spice plants and for flavouring (see Hammer et Khoshbakht, in prep.), as e.g. *A. mutellina* Vill. (W 2) for flavouring the liqueur genepí in Southern France and Northern Italy.

Sweeteners

Compositae usually have high amounts of fructans in their underground storage organs. Inulin is well known as a sweetener. It is contained in relatively high amounts in the roots of *Helianthus tuberosus*, *Inula helenium* L. (W 3), *S. sonchifolius* and *C. intybus*, well domesticated crops. *Cichorium intybus*, an important vegetable, has been selected for high inulin contents. Modern cultivars have up to 30 % inulin in their roots and are responsible for the world production of inulin, a "prebiotic" that stimulates of useful colonic bacteria and is thus health promoting.

Scorzonera deliciosa Guss. ex DC. (W 2) was formerly cultivated in Southern Italy (Calabria, Campania and Sicily) as a sweetener for ice cream.

The leaves of the South American *Stevia rebaudiana* (Bertoni) Bertoni (S 5) contain sweet tasting glycosides, much sweeter than sucrose. Today *Stevia* is cultivated in several countries to produce a sugar substitute for use by diabetics.

Animal food Compositae include important fodder and forage plants, as *Acmella oleracea* (L.) R.K. Jansen (W 2), *Ambrosia dumosa* (A. Gray) Payne (W 1), *Ericameria nauseosa* (Pall. ex Pursh) Nesom et Baird (W 2), *Mikania micrantha* H.B.K. (W 2), *Silphium perfoliatum* L. (W 2), *Simsia lagasceiformis* DC. (W 2), *Tripteris sinuata* DC. (N 0), *Viguieria stenoloba* Blake (W 2) and some other species are used as pasture plants.

Medicines Because of their richness of secondary compounds, Compositae play a very important role in medical care of man and his animals. Most of the species listed by Hammer and Khoshbakht (in prep.) are used as medicinal plants. The Complete German Commission E Monographs (Blumenthal 1998) contains the following species which are all in our compilation of cultivated species (Hammer and Khoshbakht, in prep.): *Achillea millefolium* L. (W 3) (yarrow), *Arctium lappa* L. (burdock) (var. *edule* (Sieb. ex Miq.) Mansf. is a well domesticated root vegetable—D 7), *Arnica montana* L. (W 2) and *A. chamissonis* Less. (W 3) (arnica flower), *Artemisa absinthium* (wormwood), *Calendula officinalis* L. (S 6) (calendula flower), *Chamaemelum nobil* (L.) All. (S 6) (chamomile flower), *C. intybus* (chicory), *Cnicus benedictus* L., *C. centaurea benedicta* (L.) L. (W 3) (blessed thistle), *C. scolymus* (artichoke leaf), *Echinacea angustifolia* DC. (W 1) and *E. purpurea* (L.) Moench (W 3) (Eastern purple coneflower), *E. pallida* (Nutt.) Nutt. (N 0) (pale purple coneflower), *Grindelia robusta* Nutt. (W 2) and *G. squarrosa* (Pursh) Dunal (W 2) (gumweed herb), *Inula helenium* (elecampane), *Matricaria chamomilla* (chamomile flower), *Petasites hybridus* (L.) Gaertn. (W 3) (butterbur), *Silybum marianum* (L.) Gaertn. (D 7) (milk thistle fruit), *Solidago virgaurea* L. (W 2) (goldenrod), *Tanacetum parthenium* (L.) Sch. Bip. (S 6) (feverfew), *Taraxacum officinale* sensu auct. (D 7) (dandelion, dandelion root), *Tussilago farfara* L. (W 2) (coltsfoot leaf). Compositae are mainly used for their antibiotic, antifungal, antihelmintic, antiplasmodial, expectorant, sedative, diuretic, spasmolytic, haematostatic, immunostimulatory or anti-inflammatory properties (Daniel 2006; Anderberg et al. 2007). There is an interesting connection between medicinal and food plants (Etkin 2006).

Artemisa annua L. (S 4) recently became one of the major antimalarial drugs. This old medicinal plant (quinghao) has been used in China for more than 2,000 years. The detection of the substance quinghaoso (artemisinin) in 1972 lead to its world-wide use of the drug against malaria (Foster and Johnson 2006).

Today breeding programmes are under way to improvethe amount of artemisinin in selected stocks.

For countries with a long tradition in the use of medicinal plants many of them are cultivated (as e.g. China, see Li et al. 2011 for a recent example). Generally, the use and cultivation of medicinal plants is more common in developing countries.

Materials The lack of fibers within the family has been already mentioned. There is only one species, *Xanthium strumarium*, experimentally cultivated in the CIS Republics and Germany as an oil and fibre plant after World War II. Relatively few species can serve for timbers and fire wood (see Hammer and Khoshbakht, in prep.).

Dyestaff The Compositae are rich as sources for natural dyes. The yellow to reddish dye of *Carthamus tinctorius* is used today mostly for colouring food. *Anthemis tinctoria* L. (W 3) was also used for colouring clothes. *Coreopsis tinctoria* Nutt. (S 4) is used in China for the orange dye obtained from the flowers. The Aztecs used for this purpose the flowers of *Cosmos sulphureus* Cav. (W 3). Also the floral rays of *Tagetes erecta* L. (S 4) are used for dying.

Rubber Some species are used for the production of rubber. *Parthenium argentatum* A. Gray (W 1) and possibly also *P. stramonium* Greene (N 0) have been used by the Mayas of Mexico for making balls from the rubber of the roots (Simpson 2009), which is similar to the rubber obtained from the most important world source *Hevea* spp. (Euphorbiaceae). After World War I trials were under way to develop crop plants for latex production from local Eurasiatic species. Some *Taraxacum* species were found for this purpose as *T. kok-saghyz* Rodin (W 3), *T. hybernum* Steven (W 1) and *T. megalorhizon* (Forssk.) Hand.-Mazz. (W 1) and suitable lines have been selected especially in the former Soviet Union. The production of rubber lost in interest after World War II. Today most of the breeding material has been lost and may only exist in large collections. New efforts are under way for developing an alternative rubber crop from *T. kok-saghyz* (van Beilen and Poirier 2007; Kirschner et al. 2013).

Successful trials for rubber production from the roots have also be done with *Chondrilla ambigua* Fisch. ex Kar. et Kir. (N 0), *Ch. pauciflora* Ledeb. (N 0), *Grindelia camporum* Greene (W 1), *Scorzonera tau-saghyz* Lipschiz ex Bosse (W 1) and *Solidago leavenworthii* Torr. et Gray (W 1) proving potentials of the family for seeking new rubber sources in the light of allergenic reactions against *Hevea*.

Environmental Compositae play also a role in landscaping. They are planted as windbreak, e.g. *Olearia solandri* Hook. f. (W 2) and are also used as hedge plants (see Hammer and Khoshbakht, in prep.).

Others Pesticides and poisons. Compositae are rich in secondary substances to fight against their natural animies. Among the first used insecticides was pyrethrin from *Tanacetum coccineum* (Willd.) Grierson (S 5) in Persia, later on the closely related *Tanacetum cinerariifolium* (Trevir.) Sch. Bip. (D 8) proved to be of higher effectiveness with lower toxicity to mammals and birds. On a more local scale *Erigeron longipes* DC. (W 2) and *Gynura procumbens* (Lour.) Merr. (W 2) are grown for their ability to kill insects.

Tagetes spp. are used to fight against nematodes.

Only two species are world crops in the definition of Hammer (Hammer 1999, see also Khoshbakht and Hammer 2008a): *L. sativa* and *H. annuus* but with respect to the healthy nutrition the world importance of some other Compositae will certainly increase.

Ethnobotanical aspects Ethnobotany covers aspects of plant use by man mostly with little consideration of cultivated plants. As there is a logical connection between knowing and using the plants and their final cultivation for a more reliable use, results from ethnobotanical studies can be taken as a hint for a possible cultivation of selected species. Through continuous collecting and use, certain selection pressures have been executed towards a pre-domestication (Hammer 1988; Laghetti 2009).

Within the Compositae many of the wild growing species are used medicinally. In China 500 of such species have been reported by Caligari and Hind (1996). Many of them can be found also as cultivated, see Li et al. (2011). In Mexico about 180 species of Compositae are employed in traditional medicine (Caligari and Hind 1996). The connection between the use of wild medicinal plants and their introduction into horti- and agriculture is elaborated by Logan and Dixon (1994). Often Compositae are collected and used as wild vegetables (Bye 1981; Moreno-Black et al. 1996; Lev-Yafun and Abbo 1999; Marshall 2001).

Mostly all uses mentioned above are also known from ethnobotanical reports.

Negative economic significance Many Compositae are known as noxious weeds and immigrants. The more relevant genera in this respect are: *Acroptilon, Carduus, Cirsium, Centaurea, Onopordon, Chondrilla, Parthenium, Ambrosia, Chromolaena, Mikania, Chrysanthemoides* and *Senecio*.

Parthenium hysterophorus L. from North America, which is also invasive in Australia, causes a serious contact dermatitis (Anderberg et al. 2007).

Artemisia spp., some species are also cultivated (see Hammer and Khoshbakht, in prep.), belong to the most common sources for hay-fever in the US with a tendency to be invasive elsewhere.

Some toxic plants for livestock are also known, as *Senecio* spp.

Leguminosae Juss.

This family belongs to the Fabales together with the Surianaceae (tropical regions, no cultivated species, source of an excellent carving wood), Polygalaceae (tropical, subtropical and temperate regions, a few cultivated species, mostly medicinal plants) and Quillajaceae (warm-temperate S America, the bark of one species is used saponin production from wild stands) (Kubitzki 2007). Quillajaceae and Surianaceae are small families. Polygalaceae comprise roughly 1,000 species.

The big family of Leguminosae shows a large distribution, only Antarctica is not included. Three subfamilies are considered, the Caesalpinioideae and Mimosoideae are predominantly tropical whereas the Papilionoideae, the most important group with respect to human use, are quite common in temperate regions. Certainly the Leguminosae belong to the largest families. Their economic importance is not larger than that of the Gramineae, but they exceed them in the range of uses (Doyle and Luckow 2003). They provide "food (for animals and humans), and drink, pharmaceuticals and medicine, biodiesel fuel, biotechnology (as industrial enzymes), building and construction, textiles, furniture and crafts, paper and pulp, mining, manufacturing processes, chemicals and fertilizers, waste recycling, horticulture, pest control, and eco-tourism" (Lewis et al. 2005). Leguminosae cover 27 % of the world's primary crop production with grain legumes alone (12–15 % of the world's arable lands) and 33 % of the dietary protein nitrogen needs of humans (Graham and Vance 2003).

Leguminosae are very often with N-fixing root nodules distributed throughout the family. They are able to perform symbiotic nitrogen fixation by symbiosis with *Rhizobium* bacteria. Many species of the family are, therefore, used as soil improvers, stabilizers, as green manure and for landscape improvement. This ability of nitrogen fixation can be only occasionally found in other families.

The Phaseoleae (Papilioideae) can be seen as the most important group containing cultivated plants, followed by Ingeae (Mimosoideae) and Cassieae (Caesalpinioideae). Thus all three subfamilies posses larger numbers of cultivated species.

Certainly the range of uses in the Leguminosae is broader than that of the grass family (Gramineae) (Doyle and Luckow 2003). Their already mentioned symbiosis with nitrogen-fixing bacteria is of supreme importance (Sprent and McKey 1994).

Food Leguminosae are very important as food for humans. Many of them are crops of world importance (see selected cases). Seeds and fruits are eaten, prepared in different ways. The high contents of proteins and often fats is characteristic for this food. This is of particular value for protein-deficient areas of the world. *Glycine max* (H 18) with high protein and oil contents became one of the main crops in E Asia, also as a substitute for cow milk. The New World crop *Arachis hypogaea* (H 18) (peanut) became an important world crop. The unripe fruits together with the seeds are eaten as a vegetable in a number of species: *Phaseolus* spp., *Pisum sativum* (H 15), *Lablab purpureus* (H 15), *Canavalia* spp., *Vigna* spp. Some species are cultivated for their starchy root tubers, as *Pueraria* spp., *Pachyrhizus* spp., *Apios americana* Medik. (D 7), *Sphenostylis* spp., *Flemingia vestita* Benth. ex Bak. (W 3), *Lathyrus tuberosus* L. (W 2).

Spice There are only few spice plants in the family. The roots of *Glycyrrhiza lepidota* (Nutt.) Pursh (W 2) have been formerly collected by tribes of N American Indians and used as spice and medicine. *Glycyrrhiza glabra* L. (S 5) produces liquorice in roots and rhizomes, the Eurasiatic species was used since olden times as a medicinal plant. Later on, the roots were taken for flavouring beverages, chocolate, tobacco and in cosmetics. The production is restricted to a few specialized factories in Italy, Spain and Greece. *Melilotus macrocarpus* Coss. et Dur. (W 2) is cultivated for its spicy pods in Algeria. *Trigonella caerulea* (L.) Ser. (D 8) was traditionally used in Europe as a spice crop. It has been used for flavouring a greenish cheese, bread and other dishes. Today it is restricted to parts of the Alps and the Caucasus, where it is also applied in folk medicine, as a magic plant and as an insecticide. More important is *Trigonella foenum-graecum* L. (H 11), the seeds of which are taken for flavouring bread, beverages and butter. It is grown in Eurasia, parts of Africa and also in the Americas. In India the young leaves are eaten as a vegetable.

Animal food Leguminosae are important for feeding livestock. The green parts of many species, among them very important forage plants (e.g. *Medicago, Trifolium* etc.), are rich in nitrogen. The same is true for the seeds which are very useful in animal nutrition. Many examples for forage and fodder plants can be found in Hammer and Khoshbakht, in prep.

Medicines Within the Leguminosae the use as medicines is well known. Many species are used as insecticides, molluscides, abortifaciens, purgatives, aphrodisiacs and hallucinogens, antiinflammatories and antiseptics (Lewis et al. 2005).

Materials Tanbarks are very common in the family (*Acacia* spp., *Gleditschia* spp., *Caesalpinia* spp., *Cassia* spp., *Bauhinia purpurea* L. (S 4). They also provide copals, gum, dyes (*Cassia* and *Senna* spp.), kino and insecticides. Indigo obtained from *Indigofera* spp. played an important role in the production of blue dye until the detection of the chemical synthesis of such dyes. Today the production of natural dyes is again increasing. Fiber plants are not common within the family: *Bauhinia purpurea L.* (S 4), *Wisteria* spp., *Pueraria* spp., *Sesbania* spp., *Crotalaria* spp. *Spartium junceum* L. (W 3). *Vigna unguiculata* var. *textilis* (A. Chev.) K. Hammer was especially selected in Africa for making fiber from the long peduncles. From the stems of this species no usable fibres are produced. *Hardwickia binata* Roxb. (W 2), *Entada phaseoloides* (Stickm.) Merrill (S 4) and *Derris trifoliata* Lour. (W 3) are cultivated for their bark fibres. Mostly, they are made into ropes (Lewis et al. 2005).

Environmental The symbiosis with root bacteria which are able to bind nitrogen from the air makes most of the Leguminosae important in land improvement and green manuring. For this purpose they combine in an excellent way with Gramineae, which are effective consumers of nitrogen. Leguminosae belong to the most important plants for landscaping.

Others Several species are used to stupefy fishes: *Platymiscium* spp., *Derris* spp., *Lonchocarpus nicou* (Aubl.) DC. (S 5), *L. urucu* Kilip et Sm. (S 5), *Milletia ichthyotona* Drake (W 2), *Mundulea* spp., *Tephrosia* spp. The aromatic resin of the stem of *Hymenaea courbaril* L. (W 3) is used medicinally. In the same way also *Copaifera* spp. (*C. officinalis* L. (W 2)—copaiba balsam) and *Trachylobium* spp. (today often included in *Hymenaea*) are used.

World crops The family is the second one with respect to world crops after Gramineae. The following species and species groups are considered: *Phaseolus* spp., *Glycine max, Vigna* spp., *Arachis hypogaea*, *Lens culinaris, Pisum sativum*, *Cicer arietinum* (all in Table 2).

Cultivated ornamental plants Only relatively few species of the family are marketed as cut flowers, among them the florist's mimosa (*Acacia dealbata* Link) and sweet peas (*Lathyrus odoratus* L.). More important are ornamental trees in the Tropics and Subtropics, which are often planted in parks, gardens and as road trees, as *Albizia, Caesalpinia, Calliandra, Cassia, Castanospermum, Delonix, Mucuna, Senna, Tipuana, Strongylodon*. In a book on recently introduced new trees to cultivation there are a number of species from the following genera: *Acacia, Albizia, Ceratonia, Cercis* and *Leucaena* (Grimshaw and Bayton 2009).

Ethnobotanical aspects Over a quarter of all species from the family belong to only five genera: *Acacia, Astragalus, Crotalaria, Indigofera* and *Mimosa*. These genera also constitute the majority of cultivated species. At the same time they are of great interest for the ethnobotanists (Pickersgill and Lock 1996).

Table 2 Highly domesticated taxa (H) in Leguminosae

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
	Pu. (s.); Ve.	2	4	4	3	3	16	H
Arachis hypogaea L.	Oi. (s.); Pu. (s.); Fo.; I.; Ru.	3	4	4	3	4	18	H
Cajanus cajan (L.) Huth	Ve. (s., pods); Gm.; He.; Fo.	2	4	4	2	2	14	H
Canavalia ensiformis (L.) DC.	Ve. (s., pods, l.); Gm.; M.	1	3	4	1	1	10	H
Canavalia gladiata (Jacq.) DC.	Ve. (s., pods); Gc.; Gm.; Fo.	2	3	4	1	1	11	H
Ceratonia siliqua L.	M. (fr., l.); I. (st., l.); Fl.; D.	2	3	4	2	1	12	H
Cicer arietinum L.	Pu. (s.); Ve.	2	4	4	3	3	16	H
Crotalaria juncea L.	Fi.; Gm.; Gc.; Fo.	1	4	4	1	1	11	H
Cyamopsis tetragonoloba (L.) Taub.	Ve. (l., s., pods); Gm.; Gc.; M.; Gum; Pu.; I.	2	4	4	3	3	16	H
Glycine max (L.) Merr.	Ve.; Oi.; Gm.	2	4	4	4	4	18	H
Lablab purpureus (L.) Sweet	Ve. (green pods, s., l.); Fo.; Gm.; Gc.	2	4	4	3	2	15	H
Lathyrus sativus L.	Fo.; Gm.; Fd. (s.); Pu.	1	3	4	2	2	12	H
Lens culinaris Medik.	Ve. (pods); Fo.; Gm., Pu.	1	4	4	3	3	15	H
Lupinus albus L.	Gm.; Fo.; Pu.	1	3	3	1	2	10	H
Lupinus mutabilis Sweet	Or., Pu.	1	2	4	1	1	9	H
Macrotyloma uniflorum (Lam.) Verdc.	Gm.; Fo.	1	3	4	1	1	10	H
Medicago sativa L. subsp. *sativa*	Fo.; Gm.; Ve.; Pu.; Or.; M.	2	4	4	2	3	15	H
Medicago sativa subsp. × *media* (Pers.) Schübl. et Mert.	Fo.	2	3	3	2	3	13	H
Mucuna pruriens (L.) DC. subsp. *deeringiana* (Bort) Hanelt	Pu.	3	3	3	3	2	14	H
Neonotonia wightii (Arn.) Lackey	Fo.; Gc.; Gm.	4	4	2	3	1	14	H
Phaseolus coccineus L.	Pu. (r., s., pods); Ve.; Or.	2	4	4	2	1	13	H
Phaseolus lunatus L.	Ve. (s., l.); Gm.; Gc.	3	4	4	3	2	16	H
Phaseolus vulgaris L.	Ve. (s.); Pu.	4	4	4	3	4	19	H
Pisum sativum L.	Ve.; Gm.; Pu. (pods); Fo.	2	3	4	3	3	15	H
Psophocarpus tetragonolobus (Stickm.) DC.	Ve. (fl., st.); Pu. (r.)	1	4	3	2	2	12	H
Tamarindus indica L.	D.; Fo. (l.); Ve. (fr., l., fl.); I.; M.	1	4	3	2	1	11	H
Trifolium alexandrinum L.	Gm.; Fo.	1	3	3	1	2	10	H
Trifolium incarnatum L.	Fo.	1	3	3	1	2	10	H
Trifolium pratense L.	M.; Fo.	1	3	3	1	2	13	H
Trifolium repens L.	Fo.; Gm.; honey	2	4	2	2	2	12	H
Trifolium resupinatum L.	Fo.; Gm.; Ve.	1	3	3	1	2	10	H
Trifolium subterraneum L.	Fo.	1	3	3	1	2	10	H
Trigonella foenum-graecum L.	M.; Ve. (l.); Gm.; Fo.	1	3	4	2	1	11	H
Vicia faba L. var. *minor* Peterm.	Gm.; Fo.; Pu.	1	3	4	1	2	11	H
Vicia faba var. *equina* (Medik.) Pers.	Pu.	1	3	4	1	1	10	H
Vicia faba var. *faba*	Pu.; Ve.; Fo.	1	3	4	2	2	12	H
Vigna angularis (Willd.) Ohwi et Ohashi	Ve.; M.; Fo.; Gm.	2	3	4	2	2	13	H
Vigna mungo (L.) Hepper	Ve. (pods); Fo.; Gm.	3	3	4	2	2	14	H
Vigna radiata (L.) Wilczek	Ve.; Pu.; Fo.; Gm.	3	3	4	2	2	14	H

Table 2 continued

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Vigna umbellata (Thunb.) Ohwi et Ohashi	Ve. (s., l., pods); Fo.; Gm.	1	3	4	1	1	10	H
Vigna unguiculata (L.) Walp.	Ve. (l., pods); fo.; Gm.; Fi.	4	4	4	4	3	19	H

[a] D.: Dye plant; Fi.: Fibre crops; Fl.: Flavours; Fo.: Fodder crops; I.: Industrial crops; Gc.: Ground cover; Gm. Green manure; M.: Medicinal; Oi.: Oil crops; Or.: Ornamental; Ve.: Vegetable; He. : Hedge plant; Ru: Rubber; Fd.: Food and Food additive; Pu.: Pulses

[b] (fl.): Flowers; (fr.): Fruits; (l.): Leaves; (r.): Roots, rhizomes; (st.): Stem; (s.): Seeds

[c] A: Phenotypic differentiation; B: Extent of cultivation; C: History of cultivation; D: Major genetic alterations; E: Improvement through breeding

[d] H: Highly domesticated >9; D: Domesticated 7–9; S: Semi domesticated 4–6; W: Weakly domesticated 1–3; N: Not domesticated 0

Negative economic significance Many species which have been introduced for ornamental use or landscaping become weedy and invasive as *Acacia* spp., *Dichrostachys, Leucaena, Mimosa, Pueraria* and *Sesbania*.

Orchidaceae Juss.

For a long time the Orchidaceae have been considered as the largest family. In addition, even in a recent account they are seen in this position (Heywood et al. 2007). Some estimations reached 800 genera and 35,000 species. However, mostly, today the Compositae are taken as the largest family with over 1,600 genera and 23,000 species (and in addition a great number of apomictic microspecies) (Anderberg et al. 2007). The Orchidaceae have a worldwide distribution. They are only absent from extreme environments as very dry deserts and high mountains. Epiphytes predominate in temperate regions, whereas under colder climates terrestrial life-forms prevail. Orchidaceae are specialized in many respects. They have highly adapted flowers to different pollinators (as an extreme pseudocopulation in *Ophrys* can be seen, *Angraecum sesquipedale* Thouars from Madagascar has 30 cm long spurs in adaptation to a moth with very long proboscis, there are also cleistogamous flowers developing under the soil), they have developed different forms of mycotrophy with the extreme of achlorophyllous taxa with reduced root system, e.g. *Neottia* Guett., the tiny seeds with endosperm development arrested at an early stage are adapted to various dispersal mechanisms and usually need a specialized species of fungus for germination, the roots can become assimilating organs and many other adaptations. Usually the biomass of the populations is not high, but there are reports about *Grammatophyllum* Blume, forming gigantic clusters reaching several hundred kilograms. *Sobralia altissima* D.C. Bennett et Christenson, recently described from Peru, reaches a height of up to 13.4 m.

Mostly five subfamilies are accepted for the Orchidaceae. Only three subfamilies appear in Table 3, subfam. Orchidioideae with the genera *Corymborkis* and *Anoectochilus*, subfam. Vanilloideae with several species of *Vanilla* and subfam. Epidendroideae with several tribes containing all the other species.

Highly domesticated crops are not available within the Orchidaceae considered here. Only *Vanilla planifolia* has been evaluated as D, and there are some cases of S (see Table 3). Within the cultivated ornamentals there are certainly some cases of highly domesticated species (H).

Food The tubers of many orchids are collected and eaten, also as an aphrodisiac (salep) especially in the Near and Middle East. *Orchis mascula* L. is also cultivated for this purpose. The roasted bulbs of cultivated *Dactylorhiza majalis* are eaten as a vegetable in Nepal. But most of the cases report about use and collection of wild plants, as e.g. *Orchis morio* L., *O. purpurea* Huds., *O. mascula* L., *O. militaris* L., *O. ustulata* L., *Gymnadenia conopsea* (L.) R. Br., *Platanthera bifolia* (L.) Rich, *Anacamptis pyramidalis* (L.) Rich., and species of *Aceras* R. Br., *Cephalanthera* Rich., *Epipactis* Zinn, *Himanthoglossum* Spreng., *Limodorum* L., *Nigritella*

Table 3 Domesticated taxa in Orchidaceae

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Anoectochilus formosanus Hayata	M. (bu.)	0	1	1	1	1	4	S
Anoectochilus koshunensis Hayata	M. (bu.)	0	1	1	1	1	4	S
Bletilla striata (Thunb.) Rchb. f. (*B. gebinae* Rchb. f.)	M.; Or.	0	2	3	0	0	5	S
Corymborkis longiflora (Hook.f.) Burkill	M. (l.)	0	1	1	0	0	2	W
Corymborkis veratrifolia (Reinw.) Blume	M. (l.)	0	1	1	0	0	2	W
Cremastra appendiculata (D. Don.) Makino	M.(r.)	0	1	1	0	0	2	W
Cymbidium ensifolium (L.) Swartz; Li et al. (2011)	M. (r., fl.)	0	2	1	0	0	3	W
Cymbidium faberi Rolfe,; see also Li et al. (2011)	M., Fl. (fl.)	0	1	1	0	0	2	W
Cymbidium hookerianum Rchb. f.; Li et al. (2011)	Fl. (fl.)	0	1	1	0	0	2	W
Cymbidium longifolium D. Don; Li et al. (2011)	M. (h.)	0	2	2	0	0	4	S
Cymbidium sinense (Andr.) Willd.; Li et al. (2011)	Fl. (fl.)	0	2	2	0	0	4	S
Cymbidium virescens Lindl., syn. *C. goeringii* (Rchb. f.) Rchb. f.; see Li et al. (2011)	Ve.(fl.); Fo.	0	1	3	0	0	4	S
Dactylorhiza maculata (L.) Soó	M. (bu.)	0	1	1	0	0	2	W
Dactylorhiza majalis (Rchb.) P.F. Hunt et Summerhayes	M. (bu.)	0	1	1	0	0	2	W
Dendrobium aduncum Lindl.	M.	0	1	2	0	0	3	W
Dendrobium aggregatum Roxb.	M.; Or.	0	1	1	0	0	2	W
Dendrobium aphyllum (Roxb.) C.E.C. Fisch.	M.; Or.	0	1	1	0	0	2	W
Dendrobium bellatulum Rolfe	M.	0	1	2	0	0	3	W
Dendrobium ceraia Lindl.	M.	0	1	2	0	0	3	W
Dendrobium lohohense Tang et Wang	M.	0	1	2	0	0	3	W
Dendrobium moniliforme (L.) Sw.	M.	0	1	2	0	0	3	W
Dendrobium nobile Lindl.	M.	0	1	4	0	0	5	S
Dendrobium plicatile Lindl.	M.	0	1	2	0	0	3	W
Dendrobium pulchrum Schlechter	I.; Fi.	0	1	1	0	0	2	W
Epipactis helleborine (L.) Crantz	M. (bu.)	0	1	1	0	0	2	W
Eria graminifolia Lindl.; Li et al. (2011)	M. (h.)	0	1	2	0	0	3	W
Gastrodia elata Blume; see also Li et al. (2011)	M.(bu.)	0	1	1	0	0	2	W
Holcoglossum falcatum (Thunb.) Garay et H. Sweet, syn. *Neofinetia falcata* H.H. Hu	Pe.	0	1	3	0	0	4	S
Holcoglossum kimballianum (Rchb. f.) Garay	Or.; M.	0	1	1	0	0	2	W
Luisia filiformis Hook.f.	M.	0	1	1	0	0	2	W
Nervilia aragoana Gaud.; Li et al. (2011)	M. (bu.)	0	1	2	0	0	3	W
Pholidota imbricata Lindl.	M. (bu.)	0	1	1	0	0	2	W
Rhynchostylis retusa (L.) Blume	M.	0	2	1	0	0	3	W
Vanilla abundiflora J.J. Sm.	Ar. (fr.)	0	1	1	0	0	2	W
Vanilla albida Blume	M.; food. (fr.).; latex	0	1	1	0	0	2	W
Vanilla claviculata Sw.	M.(l.)	0	1	1	0	0	2	W
Vanilla gardneri Rolfe	Ar.(fr.)	0	1	1	0	0	2	W
Vanilla phaeantha Rchb.f.	M.; Fl. (fr.)	0	1	2	0	0	3	W
Vanilla planifolia Andr.; see also Li et al. (2011)	Fl. (fr.)	1	3	3	1	1	9	D
Vanilla pompona Schiede	Fl. (fr.)	0	1	1	0	0	2	W

Table 3 continued

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Vanilla tahitiensis J.W. Moore	Ar.; Fl. (fr.); Fo.	0	1	2	0	0	3	W

[a] Ar.: Aromatic; Fi.: Fibre crops; Fl.: Flavours; Fo.: Fodder crops; I.: Industrial crops; M.: Medicinal; Or.: Ornamental; Ve.: Vegetable; Pe.: Perfume

[b] (fl.): Flowers; (fr.): Fruits; (h.): Herb; (l.): Leaves; (r.): Roots, rhizomes; Bulbs (bu.)

[c] A: Phenotypic differentiation; B: Extent of cultivation; C: History of cultivation; D: Major genetic alterations; E: Improvement through breeding

[d] H: Highly domesticated >9; D: Domesticated 7–9; S: Semi domesticated 4–6; W: Weakly domesticated 1–3; N: Not domesticated 0

Rich., *Ophrys* L., *Habenaria* Willd. and *Eulophia* Agardh (Keller 2001). Mostly the orchids are more considered as edible medicines (in the sense of Etkin 2006) but in some cases the food function prevails. *Vanilla albida* is grown in South-East Asia for their large sweet edible fruits. Pseudobulbs and leaves of *Cymbidium virescens* are used in Japan as a vegetable. They are also collected from the wild.

Beverages The flowers of *Cymbidium virescens* (see Table 3) are salted and put into hot water for making a drink. The fruits of some *Vanilla* species are used to flavor beverages.

Spice The flowers of some orchids are used as spice, especially some *Cymbidium* spp.

Animal food Leaves and pseudobulbs are usually taken from wild stands, in a few cases also from cultivated plants, e.g. *Cymbidium virescens*.

Medicinals Nearly all parts of cultivated Orchidaceae are used medicinally (see Table 3). In E Asia some *Dendrobium* spp. are cultivated to produce the drug "shih-hu" used for fever, cough, dry mouth and thirst. Reports are about its tonic action for lungs and stomach and as an aphrodisiac. This traditional drug is exported in tons. Main sources are *Dendrobium nobile* and also *D. lohohense, D. plicatile, D. ceraia, D. aduncum* and *D. bellatulum* (Keller 2001).

Materials *Holcoglossum falcatum* has been cultivated since ancient times in Japan as a perfume plant, the same is true for *Dendrobium moniliforme*. Several species of *Cattleya* are cultivated in Bangladesh for their pollinia. Large amounts are transported to France for the preparation of cosmetics (Lawler 1984).

The latex from the fruits of *Vanilla albida* is used as a hair tonic (Lawler 1984). Orchids are rarely used for their fibres. *Dendrobium pulchrum* in Papua New Guinea is transplanted to trees around the settlements by local inhabitants. The fibres of the dried stems are used for weaving (Lawler 1984). This is a kind of semi-cultivation and can lead, over the long range, to first steps of domestication (Keller 2001).

World Crops No real world crops can be found from this family. *Vanilla planifolia* (Bourbon vanilla) has some world importance as an aromatic plant. The unripe fruits get fermented and develop the typical flavor of *Vanilla* caused by vanillin. Already cultivated by the Aztecs to flavour cocoa. *Vanilla tahitiensis* (Tahiti vanilla) from the Polynesian islands has a sweeter aroma than *V. planifolia* and is used for flavouring sweets, ice-cream, confectionary, beverages, other food and for cosmetics (Keller 2001).

Cultivated ornamental plants The members of this family have often beautiful flowers and sometimes also leaves. Many species kept as ornamentals in tropical and subtropical house gardens. An old center for cultivated ornamental Orchids has developed in East Asia. Examples can be found in Table 3, especially from the genera *Dendrobium* and *Cymbidium*. After the biotechnological progress in growing of Orchidaceae, their number under cultivation raised considerably. The lack of crossing barriers lead to many new economic hybrids. In Europe and N America this is especially true for Orchidaceae under glass but also the number for out-of-doors planting is tremendously increasing in the last decennia. Cullen et al. (2011) report in Europe 28 genera for out-of-doors planting. Altogether Cullen et al. (2011) report about 179 genera and 1,037 species of Orchidaceae cultivated exclusively as ornamentals in Europe. For South Africa Glen (2002) reports about 108 genera and 382 species of cultivated Orchidaceae. Principally nearly all epiphytic and an increasing part of the terrestrial Orchidaceae are seeked for by amateurs, who are willing to pay exorbitant amounts for rare and new plants. Therefore the biodiversity of the orchids is often endangered and strict rules of CITES and controlled and regulated orchid trade have been developed (Roberts et al. 1995–2002). The USA play the leading part in the huge floriculture industry with orchids.

Ethnobotanical aspects The circumpolar orchid *Calypso bulbosa* (L.) Oakes was formerly used in North America for their edible bulbs. This and other ethnobotanical uses have been meticulously reported by Lawler (1984). There are wild aroma producers from the genus *Vanilla*, as *V. ensifolia* Rolfe, *V. guaiensis* Split, *V. palmarum* Lindl., *V. duckei* Huber, *V. eggersii* Rolfe, *V. odorata* Presl and *V. parvifolia* Rodrig. Traditional cultivation has been only reported from limited areas of the world, as East Asia. The fungus *Armillariella mellea* (Vah. ex Fr.) Karst. (Tricholomataceae) is used to prepare the substrate for *Gastrodia elata* since 470 AD. but most of the other cases are reported as a kind of semi-cultivation.

Negative economic significance Orchidaceae avoid usually the habitats of human agri- and horticulture by their epiphytic growth or rather low development. Therefore, no reports are available in this respect.

A contact dermatitis was reported for *Cypripedium calceolus* L.

Rubiaceae Juss.

Classification and principle genera of this large family are still under discussion. Mostly four subfamilies are considered. Three of them contain several genera with cultivated plants, they are Cinchonoideae (cultivated genera: *Adina, Bouvardia, Calycophyllum, Cinchona, Hymenodictyon*, *Isertia, Mitragyna, Nauclea, Sarcocephalus, Uncaria*), Ixoroideae (cultivated genera: *Alibertia, Borojoa, Coffea, Duroia, Gardenia, Genipa, Heinsia, Ixora, Mussaenda, Posoqueria, Psilathus, Randia, Rothmannia, Vangueria*) and Rubioideae (cultivated genera: *Galium, Hamelia, Hedyotis, Morinda, Palicourea, Psychotria, Richardia, Rubia, Serissa, Spermacoce*). Subfamily Antirheoideae contains only a few cultivated genera (*Canthium, Ritigynia*, *Craterispermum*). For a detailed enumeration of the cultivated species see the following Table 4.

The family has a cosmopolitan distribution and reaches subpolar regions. But it is most diverse in the tropical and subtropical regions, mostly with trees, shrubs and lianes. Myrmecophily is rather common. Often with chemical repellents (i.e. isochinoline alkaloids). Therefore, species of this genus are often used as medicinal plants.

Only *Coffea arabica* can be considered as highly domesticated (H).

Food Members of the Rubiaceae are not common as human food, though the fruits of *Coffea* spp. are eaten in large amount during their picking, but probably more for their alkaloids than their sugar content. Some species are eaten as leaf vegetable, as *Heinsia pulchella* and *Mussaenda frondosa* (all author names and domestication assessments can be found in Table 4) and other *Mussaenda* spp. Some species have edible fruits as *Morinda citrifolia*, *Vangueria madagascariensis*, *Canthidium longiflorum* and *Boroja* spp. *Genipa americana* is grown for its edible fruits in S America.

Beverages The importance of coffee is explained under world crops. *Galium odoratum* is used for flavouring beer and soft drinks in many parts of Europe.

Animal food Only a few species are used as forage and fodder plants for animals: *Richardia scabra, Randia ruiziana*, *Isertia coccinea* and *Posoqueria longiflora*.

Medicinals Rubiaceae are rich in alkaloids and other substances. They are often used as medicinal plants. The most important is *Psychotria ipecacuanha* an emetic, amoebicide and expectorant. *Uncaria gambir* is also used as a medicinal. An aphrodisiac is obtained from *Pausinystalia yohimbe* (K. Schum.) Beille which is going to be cultivated. Many species have a medicinal use, e.g. *Gardenia jasminoides* which is known (whole plants) as antispasmotic, antiperiodic,

Table 4 Domesticated taxa in Rubiaceae

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Adina cordifolia (Roxb.) Benth. et Hook. f.	M.	0	1	1	0	0	2	W
Alibertia edulis (L.C. Rich.) A. Rich.	Fo. (fr.)	0	2	1	0	0	3	W
Alibertia myrciifolia K. Schum.	M.; Fo.	0	1	1	0	0	2	W
Alibertia verrucosa S. Moore	M.	0	1	1	0	0	2	W
Borojoa patinoi Cuatrec.	M. (fr.)	0	1	1	0	0	2	W
Borojoa sorbilis (Ducke) Cuatrec.	Fr. (fr.)	0	1	1	0	0	2	W
Borojoa stipularis (Ducke) Cuatrec.	Fr. (fr.)	0	1	1	0	0	2	W
Borojoa verticillata (Ducke) Cuatrec.	Fr. (fr.)	0	1	1	0	0	2	W
Bouvardia ternifolia (Cav.) Schlecht.	M.	0	1	0	0	0	1	W
Calycophyllum candissimum (Vahl) DC.	M.	0	1	1	0	0	2	W
Canthium horridum Blume	He., M.(l., ba., fr.)	0	1	1	0	0	2	W
Canthium lanciflorum Hiern	Fr. (fr.)	0	2	1	0	0	3	W
Canthium subcordatum DC.	He.	0	1	1	0	0	2	W
Catunaregam spinosa (Thunb.) Tirveng.	He., M.(ba., fr.)	0	1	1	0	0	2	W
Catunargam tomentosa (Blume ex DC.) Tirveng	He., M.(fr.l.)	0	1	1	0	0	2	W
Cinchona calisaya Wedd.	M.	1	3	2	0	1	7	D
Cinchona micrantha Ruiz et Pav.	M.	0	1	1	0	0	2	W
Cinchona officinalis L.	M. (l.)	1	3	2	0	0	6	S
Cinchona pubescens Vahl	M. (cortex); Ve.	1	2	2	0	1	6	S
Coffea × *arabusta* Capot et Aké Assi	M., beverage	1	2	1	0	1	5	S
Coffea abeokutae Cramer	M., beverage	0	1	1	0	0	2	W
Coffea arabica L.	M., beverage	1	3	3	1	2	10	H
Coffea bengalensis Roxb.	M., beverage	0	1	1	0	1	3	W
Coffea canephora Pierre ex Froehner	M., beverage	1	3	3	1	1	9	D
Coffea dewevrei De Wild.	M., beverage	0	2	2	0	0	4	S
Coffea eugenioides S. Moore	M., beverage	0	1	1	0	1	3	W
Coffea klainii Pierre ex De Wild.	M., beverage	0	1	1	0	0	2	W
Coffea liberica Bull	M., beverage	1	3	2	0	0	6	S
Coffea racemosa Lour.	M., beverage	0	1	1	0	0	2	W
Coffea stenophylla G. Don	M., beverage	0	2	1	0	1	4	S
Coffea zanguebariae Lour.	M., beverage	0	1	1	0	0	2	W
Craterispermum laurinum (DC.) Benth.; Jansen and Cardon (2005)	Living fences	0	1	1	0	0	2	W
Craterispermum schweinfurthii Hiern; Jansen and Cardon (2005)	Living fences	0	1	1	0	0	2	W
Duroia eriophila L. f.	Pu. (fr.)	0	1	1	0	0	2	W
Galium arenarium Loisel.	St.	0	1	1	0	0	2	W
Galium odoratum (L.) Scop.	M.; Fo.; Fl.	0	2	2	0	1	5	S
Gardenia jasminoides Ellis	Oi. (fl.); D.; M.; He.; Or.	0	2	2	0	0	4	S
Gardenia lucida Roxb.	M.	0	1	1	0	0	2	W
Gardenia nitida Hook.	M.	0	1	1	0	0	2	W
Gardenia sootepensis Hutch.; Li et al. (2011)	M. (fr., l., fl., s.)	0	2	1	0	0	3	W

Table 4 continued

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Gardenia taitensis DC.	Ar.; Oi.	0	1	1	0	0	2	W
Genipa americana L.	Fo. (fr.); D.	0	2	2	0	0	4	S
Hamelia axillaris Sw.	M. (r.); bait for fish	0	1	1	0	0	2	W
Hamelia patens Jacq.	M.; Or.; He.	0	2	1	0	0	3	W
Hedyotis umbellata (L.) Lam.	D.; M. (l., r.)	0	1	1	0	0	2	W
Heinsia pulchella (G. Don) K. Schum.	Ve. (l.); Fo. (fr.); Ar. (fl.)	0	1	1	0	0	2	W
Hymenodyction floribundum Robinson	He.	0	1	1	0	0	2	W
Isertia coccinea (Aubl.) M.H. Vahl	Fo. (fr.)	0	1	1	0	0	2	W
Ixora chinensis Lam.; Li et al. (2011)	M., Or.	0	1	1	0	0	2	w
Ixora coccinea L.	Or., M.	0	1	1	0	0	2	W
Ixora funlaysoniana Wall. ex G. Don	M.	0	1	1	0	0	2	W
Mitragyna speciosa Korth.	M. (l.)	0	1	1	0	0	2	W
Morinda angustifolia Roxb.	D.	0	1	1	0	0	2	W
Morinda citrifolia L.	D.; Shade tree; M.; Fo. (l., fr.)	0	2	2	0	0	4	S
Morinda geminata DC.	D. (r.); M.	0	1	1	0	0	2	W
Morinda lucida Benth.	D.; M.	0	1	1	0	0	2	W
Morinda officinalis How	M.	0	1	1	0	0	2	W
Morinda tomentosa Heyne	D. (r.)	0	1	2	0	0	3	W
Mussaenda frondosa L.	Ve. (l.); Gm. (l.); M. (l., fl., r.)	0	2	1	0	0	3	W
Mussaenda glabra Vahl	He.; Fo. (l.)	0	2	1	0	0	3	W
Mussaenda raiateënsis J.W. Moore	M.	0	1	1	0	0	2	W
Mussaenda roxburghii Hook. f.	He.; Or.; Ve. (l.); D.	0	1	1	0	0	2	W
Nauclea orientalis (L.) L.	M.	0	1	1	0	0	2	W
Nauclea subdita (Korth.) Steud.	He.	0	1	1	0	0	2	W
Palicourea crocea Roem. et Schult.	M.	0	1	1	0	0	2	W
Pauridiantha rubens (Benth.) Bremek.; Jansen and Cardon (2005)	Living fences	0	1	1	0	0	2	W
Posoqueria latifolia Roem. et Schult.	Walking sticks	0	1	1	0	0	2	W
Posoqueria longiflora Aubl.	Fo. (fr.)	0	1	1	0	0	2	W
Psilanthus ebracteolatus Hiern; Jansen and Cardon (2005)	Hybridizes with coffee	0	0	0	0	0	0	N
Psychotria (*Cephaëlis*) *acuminata* Karst.	M.; today included into the following species	0	1	1	0	0	2	W
Psychotria ipecacuanha (Brot.) Standley (*Cephaëlis ipecacuanha* (Brot.) Tussac., *Carapichea ipecacuanha* (Brot.) L. Andersson)	M.	0	3	2	0	0	5	S
Randia laetevirens Standl.	M.	0	1	1	0	0	2	W
Randia petensis Lundell	M.	0	1	1	0	0	2	W
Randia ruiziana DC.	Fo. (fr.)	0	1	1	0	0	2	W
Randia walkeri Pellegr.	M.	0	1	1	0	0	2	W

Table 4 continued

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication category[d]
		A	B	C	D	E		
Richardia scabra L.	Fo.; Gm.; soil cover	0	1	1	0	0	2	W
Rothmannia longiflora Salisb.; Jansen and Cardon (2005)	D. (fr.), M. (fr.)	0	1	0	0	0	1	W
Rubia cordifolia L.	M.	0	1	1	0	0	2	W
Rubia tinctorum L.	M.; D.	0	2	3	0	0	5	S
Rytigynia kigeziensis B. Verdcourt	Used to treat internal parasites	0	1	1	0	0	2	W
Sarcocephalus undulatus Miq.	He.	0	1	1	0	0	2	W
Serissa japonica (Thunb.) Thunb.; Li et al. (2011)	M. (st., l.)	0	2	1	0	0	3	W
Serissa serissoides (DC.) Druce Li et al. (2011)	M. (h.)	0	2	1	0	0	3	W
Spermacoce latifolia Aubl. *(Borreria latifolia* (Aubl.) Schum.)	Soil cover; Gc.	0	1	1	0	0	2	W
Spermacoce verticillata L. (*Borreria verticillata* (L.) G.F.W. Mey.)	Stabilization of dunes	0	1	1	0	0	2	W
Uncaria gambir (Hunter) Roxb.	Ar.; D.; Fo. (l.)	0	2	1	0	0	3	W
Vangueria madagascariensis J.F. Gmel.	Fr. (fr.)	0	2	2	0	0	4	S

[a] Ar.: Aromatic; D.: Dye plant; Fl.: Flavours; Fo.: Fodder crops; Gc.: Ground cover; Gm. Green manure; M.: Medicinal; Oi.: Oil crops; Or.: Ornamental; St.: Stabilization; Ve.: Vegetable; He. : Hedge plant

[b] (fl.): Flowers; (fr.): Fruits; (l.): Leaves; (r.): Roots, rhizomes; (st.): Stem; (s.): Seeds; Bark; (ba.)

[c] A: Phenotypic differentiation; B: Extent of cultivation; C: History of cultivation; D: Major genetic alterations; E: Improvement through breeding

[d] H: Highly domesticated >9; D: Domesticated 7–9; S: Semi domesticated 4–6; W: Weakly domesticated 1–3; N: Not domesticated 0

cathartic, anthelmintic and external-antiseptic (Natho 2001).

Mitragyna speciosa from SE Asia is cultivated in Thailand. The leaves are said to be used as a surrogate for opium.

Materials *Galium verum* L. has been used in cheese making as “vegetarian rennet”. *Gardenia jasminoides* is grown in Indian gardens for the essential oils which are obtained from the flowers. They are used for cosmetical products. Several species of *Gardenia* are used in the perfume industry.

Dyestuff and colourings From the roots of *Rubia tinctorum* a red dye is obtained (madder) which formerly had a great importance. Today, in Europe it is used mainly for local colourings, e.g. Easter eggs. In India and SE Asia *Rubia cordifolia* is cultivated as a dye plant (Indian madder). Other species have some importance as black and red dyes for ethnic use. Some importance have *Hedyotis umbellata*, *Morinda angustifolia* and other species of this genus and *Rothmannia longiflora*.

Tanning *Uncaria gambir* is used for the tanning of leather.

Negative economic significance *Sherardia arvensis* L. is a weed in fields of temperate part of Europe, where it reached together with agriculture in the Neolithic era. Today it is becoming rare. *Galium aparine* L. and *G. tricornutum* Dandy with little hooks on the schizocarps are dispersed by man and animals. They are bad weeds and difficult to control.

A few taxa are poisonous to cattle particularly in tropical and subtropical areas.

World crops *Coffea* is the only world crop within this large family (Prendergast 1999). It also belongs to the fifty plants that”changed the course of history” (Laws 2010). *Coffea* is a relatively large genus comprising about 225 species. Often *Psilanthus*, a relative of *Coffea*, is included into the genus (Davis and Stoffelen 2006).

Also quinine (*Cinchona* spp.) belonged to the more important species. Hobhouse (1999) counted it among the six plants that transformed humankind.

Cultivated ornamental plants Contrary to the limited use according to the Mansfeld approach, the family is rich in ornamental plants. In the European garden flora (Cullen et al. 2011) 44 genera with altogether 88 species are cited. Comparable numbers are reported for South Africa (Glen 2002): 34 genera and 91 species. As both areas are outside the tropics, most of the ornamentals are grown in glass houses. Important genera for ornamentals are: *Alberta, Asperula**, *Bouvardia*, *Coprosma, Galium*, Gardenia, Hamelia, Hillia, Hoffmannia, Houstonia**, *Ixora, Leptodermis*, Manettia, Mussaenda, Nertera, Pavetta, Pentas, Rondeletia, Rothmannia, Serissa, Warszewicia* and *Wendlandia*, among them are also garden plants for cooler climates (indicated by *).

Ethnobotanical aspects

There are many reports in ethnobotanic literature about medicinal plants and other uses. The use of wild plants for these purposes is very common. But in a number of species also the first steps of cultivation can be observed.

Many species of the family are useful for timber.

Gramineae Juss.

Gramineae are the largest family within the Poales (Table 5). The Poales comprise about 20,000 species and thus about one third of all monocotyledonous species (Linder and Rudall 2005). All subfamilies of Gramineae contain cultivated species, also the small subfamily of Centothecoideae has at least one species under cultivation. Grasses are an excellent case for macroevolution (Kellogg 2000). The most important subfamilies for human use are Bambusoideae, Pooideae and Panicoideae (Hammer and Khoshbakht, in prep.).

Remarks on selected Gramineae.

Food

Most of the civilizations are based on the caryopses of Gramineae which contain starch, protein and also considerable amounts of oil, in some cases. Many world crops are from this family.

The young shoots of the Bambusoideae are eaten cooked or sometimes raw as a nutritional vegetable with appreciable contents of protein (c. 7 %) and minerals. A great number of species is grown for this purpose. Special plantations are established, but also many species are harvested from the wild. A large number of species can be used for this purpose as a natural product (see Hammer and Khoshbakht, in prep). Domestication for the special purpose of young shoot use is still at the beginning.

Zizania latifolia (Griseb.) Turcz. ex Stapf (S 6) is cultivated for its swollen culms which are consumed as a vegetable. The plants are infected by a smut fungus causing a hypertrophic growth of the shoots which are consumed in China.

Saccharum officinarum and other *Saccharum* spp. are the most important crops for sugar production. The sweet stems of these grasses can be also used for fresh consumption, making syrup and similar matters. The same is true for some races of *Sorghum* and millets, e.g. *Sorghum saccharatum* (L. em. L.) Moench (S 6) and *Echinochloa stagnina* (Retz.) P. Beauv. (W 3).

Beverages

The starchy grains of many cereals are used for beer brewing, especially those of barley but also of wheat, or wine making (rice, sorghum). Sake is made from rice in Japan. The mostly bitter grains of *Sorghum nigricans* (Ruiz et Pav.) Snowden (S 4) are much used for beer and other fermented beverages in Africa.

Spice

Cympogopon citratus (DC.) Stapf (D 8) and other species of this genus can be mentioned here.

Animal food

Grasses played a special role in the co-evolution with animals (Stebbins 1981). The result have been large grass lands. Grasses are the dominant components of the savannah and prairie habitats covering c. 20 % of the world (Clayton and Renvoize 1989). Grasses can be used in pasture land, harvested as forage, fermented to silage and dried to obtain hay. The straw of harvested cereals often provides a good feed.

Table 5 Taxa of highly domesticated (H) and selected domesticated (D) Gramineae

Taxa	Uses type[a] (parts used[b])	Domestication indicators[c]					No. of indicators	Domestication categories[d]
		A	B	C	D	E		
Avena sativa L.	Fo. (st., l.).; I. (s.).; C.	2	3	4	2	2	13	H
Coix lacryma-jobi L. var. *lacryma-jobi*	C. (s.); M.; Fo.; Ha.	2	3	3	2	0	10	H
Coix lacryma-jobi L. var. *ma-yuen* (Romanet) Stapf	C.	3	2	3	3	1	12	H
Hordeum vulgare L. subsp. *vulgare*	Fo.; Fd.; C.	3	4	4	3	4	18	H
Oryza sativa L.	C.; M.; Oi.; M.;	3	4	4	3	4	18	H
Panicum miliaceum L.	C.; I.; Fo.	1	4	4	2	1	12	H
Pennisetum glaucum (L.) R. Br.	Fo.; C.	1	3	4	2	2	12	H
Saccharum officinarum L.	M.; I.	2	4	4	2	3	15	H
Secale cereale L.	Fo.; C.; Gm.	2	3	3	2	3	13	H
Setaria italica (L.) P. Beauv.	M.; C.	1	3	4	2	1	11	H
Sorghum durra (Forssk.) Stapf ex Prain	C.; Fo.	1	3	4	1	2	11	H
Sorghum nervosum Besser ex Schult.	C.; Fo. (l.).	1	3	4	1	2	11	H
Triticum aestivum L.	C.; Fo.	4	4	4	4	4	20	H
Triticum aethiopicum Jakubc.	C.; Fo.	3	1	3	3	1	11	H
Triticum carthlicum Nevski	C.; Fo.	3	2	3	3	0	11	H
Triticum dicoccon Schrank	C.; Fo.	2	2	4	2	1	11	H
Triticum durum Desf.	C.; Fo.	3	3	4	3	4	17	H
Triticum monococcum L.	Fo.; C.	2	1	4	2	1	10	H
Triticum polonicum L.	C.; Fo.	3	2	3	3	1	12	H
Triticum spelta L.	C.; Fo.	3	2	4	3	1	13	H
Triticum sphaerococcum Percival	C.; Fo.	3	1	2	3	0	9	D
Triticum turanicum Jakubc.	C.; Fo.	3	2	4	3	2	14	H
Triticum turgidum L.	C.; Fo.	3	3	4	2	1	13	H
Triticum zhukovskyi Menabde et Ericzjan	C.; Fo.	3	1	3	2	0	9	D
×*Triticosecale* Wittm.	Fo.; Fd.	2	2	2	1	2	10	H
Zea mays L.	Fo.;C.; Ve. (s.); Or.	4	4	4	4	4	20	H

[a] Fo.: Fodder crops; I.: Industrial crops; Gm. Green manure; M.: Medicinal; Oi.: Oil crops; Or.: Ornamental; Ve.: Vegetable; Fd.: Food and Food additive; Ha.: hand crafts; C.: Cereal

[b] (fr.): Fruits; (l.): Leaves; (r.): Roots, rhizomes; (st.): Stem; (s.): Seeds

[c] A: Phenotypic differentiation; B: Extent of cultivation; C: History of cultivation; D: Major genetic alterations; E: Improvement through breeding

[d] H: Highly domesticated >9; D: Domesticated 7–9; S: Semi domesticated 4–6; W: Weakly domesticated 1–3; N: Not domesticated 0

Medicinals

Medicinal plants are not common in the Gramineae. Some species of the genus *Cymbopogon* have high contents of essential oils in roots, stems and leaves. *Cymbopogon citratus* is important in Ayurvedic medicine. Other medicinally used grasses include *Zizania latifolia, Vetiveria zizanioides* (L.) Nash ex Small (S 5) and other species of the genus, *Bothriochloa odorata* (Lisboa) A. Camus (W 2), *Bambusa bambos* (L.) Voss (S 6) and *Bambusa vulgaris* Schrad. (D 8).

Materials

Oil is made from the caryopses of rice (soap making) and maize. The richness of oil in some caryopses is also used for human food and animal feed (oats). But "rice paper" is produced from *Tetrapanax papyriferum* (Araliaceae) and rice brooms from *Sorghum* *saccharatum* convar. *technicum* (Koern.) Tzvel. (S 6) and other *Sorghum* races.

Dyestuff and colourings

In some races of *Sorghum* there is a high content of anthocyan which is used for various colourings (e.g. *S. caudatum* (Hackel) Stapf ex Prain var. *colorans* (Pilger) Snowden (S 4)).

Environmental

Grasses are often planted for wild protection, dune fixation and erosion control.

Others

There are many other uses, among them necklace beads from the caryopses (*Coix*), brushes and brooms (*Sorghum*), pipe bowels (*Zea*) and clarinet reeds (*Arundo donax* L.—W 3).

World crops

The smallest of the big families appears to be extremely rich in crops of world importance. The following crops can be named: *Triticum* spp., *Hordeum vulgare*, *Oryza* spp., *Zea mays*, *Sorghum* spp., *Saccharum* spp., *Avena* spp., millets (belonging to different genera).

Cultivated ornamental plants

Many Gramineae are grown as lawn grasses (see Hammer and Khoshbakht, in prep.) and thus have developed great economic importance. Special breeds have been produced within very few species for golf areas, football places etc. Thus, species and genetic diversity is further reduced. In Europe many Bambusoideae have become garden plants in the last decennia. Cullen et al. (2011) list 94 genera and 187 species of the family, mostly as ornamentals. For South Africa Glen (2002) catalogues 56 genera and 125 species.

For ornamental use often Gramineae with variegated leaves are preferred. The diversity of leaf variegations can reach from yellow-striped to yellow–green-striped, white-banded, yellow-banded, cream-yellow-striped, white-striped and pink and white-striped (Darke and Griffiths 1994). Also the growth form and the form of inflorescences can be very attractive. There are also grasses with a specific scent. The famous German garden specialist Karl Förster wrote a book under the title “The entry of grasses and ferns into the gardens” in 1957 (Förster 1957), where he already advocated more than 100 grass species as garden plants.

Ethnobotanical aspects

Gathering foods from the wild was not so important in Gramineae, because highly domesticated species of this family were available, possibly with Australia as an exception (Isaacs 1997). In Europe, *Glyceria fluitans* (L.) R. Br. has been collected from the wild to prepare groats and in North America the Indians collected large amounts of *Zizania aquatica* L. (W 3) (which is also cultivated recently) (Maurizio 1927). Their extreme usefulness in the various categories of use will always arise the interest of ethnobotanists. Grasses are used for land-reclamation, animal food, building material, sources of paper and in many other respects. For these purposes often cultivated races are used, but there is a large range of wild species included in the different human activities. *Pennisetum riparium* A. Rich. (W 2) (syn. *P. salifex* Stapf et C.E. Hub.) was formerly burnt in Uganda to extract salt from the ashes for human consumption.

Negative economic significance

Many grasses are serious weeds and invators, as *Elymus repens, Apera spica-venti, Imperata cylindrica, Nassella trichotoma (*Nees) Arechav.*, Heteropogon contortus* (L.) Roem. et Schult*., Avena fatua* L., *A. sterilis* L. and *Poa annua*. The concept of invasive species often applies. On the other hand, weedy vegetal species often represent an early step in the unconscious evolution of crop plants, e.g. in the evolution of rye and oats.

Final discussion and conclusions

Altogether the big five families have 2.166 cultivated species (according to the Mansfeld approach) (see Table 6). The numbers and percentages of cultivated species show clear differences between the families.

Table 6 The big five families and their cultivated species (Mansfeld approach)

Families	Estimated number of species	Number of cultivated species	Percentage (%)
Compositae	c. 25,000	293	1.2
Leguminosae	c. 19,350	1,013	5.2
Orchidaceae	c. 19,000	41	0.2
Rubiaceae	c. 13,150	84	0.6
Gramineae	c. 10,000	735	7.4

For a deeper study, all species have been analysed using the domestication assessment. The method proposed by Dempewolf et al. (2008), with some changes proposed by us, can serve as a basis for evaluating the degree of domestication. The occurring differences between the methods can be explained by different material available for the investigations. From the results it becomes clear that primitive infraspecific races can be also found in crops with a high domestication index. For the evaluations, highly domesticated races have to be used and also the new trends in plant breeding should be carefully observed. Perhaps the domestication index can also clearly demonstrate differences between areas and countries (not demonstrated in this world survey).

A detailed survey on the indices for domestication levels is given in Table 7.

The percentage of cultivated Leguminosae is approaching that of Gramineae, showing the similar importance of both families as basic sources for human domestication; see also the results of Zeven and de Wet (1982). In the Near East both families, with a number of species, belonged to the first domesticates (Ladizinsky 1987). Compositae came certainly later. They have a medium position with respect to cultivated plants. The reasons for this "paradox", i.e. the great diversity of species and the limited usefulness has been been explained in great detail by Dempewolf et al. (2008). But the Compositae are of increasing importance in human nutrition. The highly specialized families Rubiaceae and Orchidaceae have rather low percentages of cultivated plants. Their special adaptation mechanisms could only be recently managed by man in developing new methods for plant production (biotechnology).

After Dempewolf et al. (2008) there is an unequal distribution of crops amongst the families of flowering plants and a link between taxonomic affiliation and likelihood of domestication. This hypothesis can be confirmed by our results. Orchidaceae and Rubiaceae have very few species in the categories H and D. Gramineae and Leguminosae show higher percentages of cultivated plants and also a high number of crops in the H, D and S categories. Compositae are between these two groups with relatively few species from the groups H, D and S, but with a rather high number from category W. This fact proves the perspective usefulness of the Compositae, mainly as source for new dietetic foods and vegetables, oils for human consumption and industrial applications and, generally, because of its richness of secondary compounds.

As already observed by Dempewolf et al. (2008) we found a distinctive suite of morphological, anatomical and physiological traits within the families which influence their suitability for domestication. With the help of modern methods (biotechnology) it will be easier to overcome some obstacles for domestication in future. Despite of all rational considerations (Hammer 2003) to increase the number of world crops by improved new species (which is possible but will be an

Table 7 Summary of domestication indicators of cultivated species in the big five families

Families	Domestication levels										
	H		D		S		W		N		Average
	Number	%	Number	%	Number	%	Number	%	Number	%	%
Compositae	10	3.4	11	3.8	30	10.2	224	76.5	18	6.1	2.6
Leguminosae	38	3.8	31	3.1	288	28.4	624	61.6	32	3.2	3.5
Orchidaceae	–	–	1	2.4	8	19.5	32	78.0	–	–	2.6
Rubiaceae	1	1.2	2	2.4	13	15.5	67	79.8	1	1.2	2.8
Gramineae	24	3.5	35	4.2	112	15.2	531	72.2	35	4.8	3.2

exception), the reverse tendency will be predominant (i.e. concentrating economy on less species). Domestication within the established world crops will follow two main lines, the creation of super-domesticates (Vaughan et al. 2007, citing cases of wheat, barley, rice, maize, sorghum, soybean, beans, pea) and the enlargement and improvement of the genetic information of important crops by introgression from other closely related species or genera (eventually creating new intergeneric hybrids like Triticale and Tritordeum).

The large and widespread family of Rubiaceae contributes even less to human welfare than the Compositae. But all four subfamilies of Rubiaceae contain at least some cultivated taxa though mostly not for food purposes.

Orchidaceae, as a large family with only relatively few cultivated species (except ornamentals), are rather different from the other monocotylous families. They have relatively few secondary compounds, but contrary to that fact, man could only draw limited use from them. This paucity of crop plants has to be seen in connection with some other adaptations of the Orchidaceae as intricate pollination system, mycorrhiza symbiosis and ecological specialisation. As cultivated food plants their use was limited. Only the skill of E Asiatic gardeners brought several species into cultivation.

The big family of grasses (Gramineae) is not rich in secondary compounds. Only relatively few grasses have toxins, as HCN or oxalates. So nothing prevented the use of many morphological similar Gramineae as food or feed. Tillers and intercalary meristems were preconditions for regrowth after burning and gracing. The relatively large fruits with their triploid starchy endosperm (possibly enlarged by co-evolution with ants and rodents), gave rise to the origins of agriculture in most of the original areas, often steppes and bushy grasslands. Gramineae have the highest percentage of cultivated plants (see Table 6). Several cereals and grasses belong to the world crops with high importance for human and animal nutrition and they are also a rich source for other uses.

Also the other family with a high percentage of cultivated species, the Leguminosae (Papilionoideae), prefers open landscapes and disturbed lands. The Leguminosae have developed a number of chemical defense mechanisms with alkaloids, tannins, terpenoids and isoflavonoids. But the chemical mechanisms are relatively easy to de-toxify or to remove by breeding. A main advantage is the symbiosis of the Leguminosae with *Rhizobium* bacteria for fixing and using the nitrogen from the air. Grain and forage legumes are cultivated on 12–15 % of the world's arable lands. They provide about 33 % of the protein for human nutrition (Mabberley 2008). Secondary compounds did not prevent their use and cultivation by man. Leguminosae compete with the Gramineae in the importance for man as main crops and have been cultivated in a great number of commodity groups.

The number of species under cultivation is clearly correlated with the content of usable carbohydrates in fruits, seeds and roots. Important key domestication traits are known mainly for the major crops and are typical for them, speeding up the selection response (Gepts 2004). This situation has been found in most of the cereals, some Leguminosae and other crops as tomatoes (Solanaceae). Many Compositae, as the typical sunflower, have been domesticated relatively late with domestication traits mostly controlled by minor QTLs (Burke et al. 2002). Speeding up the domestication can be demonstrated by the examples of super-domestication (Vaughan et al. 2007), including Gramineae and Leguminosae, but only few examples from other families as artichoke and cardoon (Compositae), tomato (Solanaceae) and banana (Musaceae).

The breeding system could be also a decisive factor for domestication. Whereas wind dispersal has negative effects for domestication (Orchidaceae, Compositae), wind pollination possibly provides a good precondition. Most of the cereals show a tendency to self fertilization. For maintaining of useful genes, self-fertilization is helpful and there may be even a selection from cross-pollination to self-pollination under cultivation, which can be demonstrated by comparing the wild progenitor with landraces and highly domesticated cultivars. Cross-pollination is often connected with self-incompatibility (especially in Compositae). Vegetative reproduction and apomictic mating systems are also securing the maintaining of useful genes during domestication. But these propagation systems are not typical for the big five families with a few exceptions, as some cultivated plants among the Gramineae (vegetative propagation, apomixis), Rubiaceae (vegetative reproduction), and Compositae (apomixis). Self-incompatibility, as a pre-condition for cross-pollinating, can be easily overcome, but some crops are foreign pollinators in spite of a long cultivation history and possible advantages by inbreeding. A general tendency can be shown. But there are many exceptions.

Relatively few founder crops have been reported. They provided the basis for starch and proteins for human consumption and produce mainly seeds or fruits (Leguminosae, Gramineae) or starchy roots and tubers. Convergent and divergent evolutionary passways have to be considered, the first of which is leading to domestication traits. Within the domesticated crop plants we have, again, an alternative—unconscious and conscious selection (Zohary 2004).

We can postulate the following steps in the pre-domestication and domestication processes:

1. Coevolution of plants and animals with respect to seed and fruits sizes (rodents, ants) and plant architecture (ruminants). Large fruits and seeds are an important incentive of use and later cultivation by man (cereals, pulses, fruit trees and shrubs). Here we can see a clear answer for the high percentages of cultivated plants within the Gramineae and Leguminosae. The same families show advantages with respect to plant architecture advantageous for steppes and grasslands. Rubiaceae and Compositae show adaptations to animal dispersal by adhesion to the fur. This was no good pre-condition for the domestication process. In the same direction acts dispersal by wind leading to very small seeds (Orchidaceae) or development of special devices (e.g. pappus) for transporting the seeds through the air. Also these seeds are not too big by airodynamic reasons (Compositae).
2. Changes of natural environments. Man as hunter and gatherer inhabitated open forests and steppe areas and started to change the landscapes. Also here, Gramineae and Leguminosae took the greatest advantage. From the steppes and open woodlands, man started to gather the fruits of grasses (Harlan 1967) and could collect an amount of grains sufficient to secure the nutritional basis for a larger population (Lips 1956).
3. Man became agri- and horticulturist. A process started, also called "neolithic revolution" (Childe 1925), which caused domestication sensu stricto, often starting from pre-adapted organisms. The traits responsible for dispersal changed rapidly. Only a few generations are needed to change from brittle to tough rachis in cereals (Fuller 2007). The same holds true for overcoming the ballistic mechanisms in Leguminosae dispersal. Intentional (conscious) selection was accompanied by unintended (unconsious) selection pressures from the agro-ecosystems (Zohary 2004). It is a far way from intended selection (mass selection, which is characteristic for field crops), and individual selection (mostly done with garden crops) to scientifically based plant breeding and other modern approaches. But the advantages gained through the former steps of man-plant-evolution towards the domestication syndrome can be followed even today.
4. Dispersal of agriculture. Agriculture was successful in the production of food and allowed an increase of the human population. Accordingly, founder crops and accompanying species got widely dispersed, thus coming into contact with other related plants. Provided the possibility that some plants tend to establish amphiploids including related species, there arose new possibilities for evolution under cultivation. Gramineae are good examples for this possibility. They formed already amphiploids (e.g. in the *Aegilops/Triticum* relationship) under pre agricultural conditions. In the Near East, one of the important founder areas for agriculture, a number of polyphyletic crops have been found (Zohary 1999).

The Compositae are relatively poor among field crops, because of different reasons discussed in detail before. In comparison with the other big families, they reach a medium level in this respect because of their morphological, anatomical, physiological traits and other reasons. But, after our investigations, they do not show a "paucity" (Dempewolf et al. 2008) of food crops in comparison with the other big families. On the other hand, they may have future importance as sources for human consumption and industrial applications. This aspect is shown in our presentation, because we did not concentrate on the founder crops alone but on many new cultivation efforts in the last 100 years. Despite of species loss and genetic erosion, new cultivated species can be detected.

After Dempewolf et al. (2008) there is an apparent link between taxonomic affiliation and percentage of cultivated species in the families. This is clearly proved by our trait assessment studies on the basis of the diversity of crop plants. Gramineae (Monocotyledons) and Leguminosae (Dicotyledons), with many founder crops for agriculture, provide examples for different crops showing a high variation. Most of the world food crops come from these families. They and their infraspecific items will be highlighted (Hammer and Khoshbakht, in prep.). As already stated, Compositae (Dicotyledoneae) reach a medium position and have less world crops than the two rich families and Rubiaceae (Dicotyledons) and Orchidaceae (Monocotyledons) have relatively low percentages of cultivated plants. World crops are exceptions, here. Both, Dicotyledons and Monocotyledons, have either high or low percentages of cultivated plants, the highest percentage is reached in the Gramineae (Monocot.) and the lowest in the Rubiaceae (Dicot.).

Gramineae usually make an effective use of the nitrogen fixed with nodulating bacteria. Thus they are adapted to mixed crops with Leguminosae and this experience has been gained in practical production systems through the last centuries. Mixed cultivation, in addition to crop rotation, with Compositae, Cruciferae and other families is now progressing (Bray 1995) as opposed to monoculture.

The analysis of diversity of plant families will be continued with detailed trait assessments in order to better understand "the patterns of domestication amongst crops, and to predict and explore the domestication potential of various floras…" (Dempewolf et al. 2008).

New ways in agriculture should not only include the consequent following of Darwinian agriculture (Pickersgill 2009; Brown 2010; Denison 2012) but also a shift to new challenge connected with biodiversity (Tilman 1999; Hammer 2003).

References

Abraham Z, Senthilkumar R, Joseph John K, Sharma TVRS, Nair NV, Unnikrishnan M, Kumaran PM, George JG, Uma S, Latha M, Malik SS, Mishra SK, Bhandari DC, Pareek SK (2008) Collection of plant genetic resources from Andaman and Nicobar Islands. Genet Resour Crop Evol 55:1279–1289

Anderberg A, Baldwin C, Bayer RG (2007) Compositae. In: Kubitzki K, Kadereit JW, Jeffrey C (eds) The families and genera of vascular plants, vol 8. Flowering plants, eudicots, asterales. Springer, Berlin, pp 61–588

Blumenthal M (1998) The complete German Commission E monographs. American Botanical Council, Austin

Bray F (1995) Modelle für die Landwirtschaft: Misch- kontra Monokultur. Spektrum der Landwirtschaft 4:74–80

Brown AHD (2010) Variation under domestication in plants: 1859 and today. Philos Trans R Soc Lond B Biol Sci 365:2523–2530

Burke JM, Tang S, Klatt S et al (2002) Genetic analysis of sunflower domestication. Genetics 161:1257–1267

Bye RA (1981) Quelites—ethnoecology of edible greens—past, present, and future. J Ethnobiol 1:109–123

Caligari PDS, Hind DJN (eds) (1996) Compositae: biology and utilization. Royal Botanic Gardens, Kew

Childe VG (1925) The dawn of European civilization. New York

Clayton WD, Renvoize SA (1989) Genera graminum. Grasses of the world. In: Kew bulletin additional series, 13, Kew

Cullen J, Knees SG, Cubey HS (eds) (2011) The European garden flora, vol 5, 2nd edn. Cambridge University Press, Cambridge

Daniel M (2006) Medicinal plants: chemistry and properties. Science Publishers, Enfield

Dansi A, Adjatin A, Adoukonou-Sagbadja H, Faladé V, Yedumonhan H, Odou D, Dossou B (2008) Traditional leafy vegetables and their use in the Benin Republic. Genet Resour Crop Evol 55:1239–1256

Darke R, Griffiths M (1994) Manual of grasses. MacMillan, London and Basingstoke

Davis A, Stoffelen P (2006) An annotated taxonomic conspectus of the genus *Coffea* (Rubiaceae). Bot J Linn Soc 152:462–512

Dempewolf H, Rieseberg LH, Cronk QC (2008) Crop domestication in the Compositae: a family-wide trait assessment. Genet Resour Crop Evol 55:1141–1157

Dempewolf H, Bordoni L, Rieseberg LH, Johannes E (2010a) Food security: crop species diversity. Science 328:169–170

Dempewolf H, Kane NC, Ostervik KL, Geleta M, Stewart ML, Lai Z, Bekele E, Cronk QC, Rieseberg LH (2010b) Establishing genomic tools and resources for *Guizotia abyssinica* (L.f.) Cass.—the development of a library of expressed sequence tags, microsatellite loci and the sequencing of its chloroplast genome. Mol Ecol Resour 10:1048–1058

Denison RF (2012) Darwinian agriculture: how understanding evolution can improve agriculture. Princeton University Press, Princeton

Doyle JJ, Luckow MA (2003) The rest of the iceberg. Legume diversity and evolution in a phylogenetic context. Plant Physiol 131:900–910

Etkin N (2006) Edible medicines: an ethnopharmacology of food. University Arizona Press, Tucson

Feyissa T, Nybom H, Bartish IC, Welander M (2007) Analysis of genetic diversity in the endangered tropical tree species *Hagenia abyssinica* using ISSR markers. Genet Resour Crop Evol 54:947–958

Förster K (1957) Einzug der Gräser und Farne in die Gärten. Neumann, Neudamm

Foster S, Johnson RI (2006) Desk reference to nature's medicine. National Geographic, Washington

Fuller DQ (2007) Contrasting patterns of crop domestication and domestication rates: recent archaeobotanical insights from the Old World. Ann Bot 100:903–924

Gebauer J, Luedeling E, Hammer K, Nagieb M, Buerkert A (2007) Mountain oases in northern Oman: an environment for evolution and in situ conservation of plant genetic resources. Genet Resour Crop Evol 54:465–481

Gepts P (2004) Crop domestication as a long-term selection experiment. Plant Breed Rev 24:1–44

Gladis T, Pistrick K (2011) *Chaerophyllum byzantinum* Boiss. and *Trachystemon orientalis* (L.) G. Don—recently introduced from Turkish wild flora as new crop species among other interesting findings from immigrant gardens in western Germany. Genet Resour Crop Evol 58:165–174

Glen HF (2002) Cultivated plants of southern Africa—names, common names, literature. Jacana, Johannesburg

Graham PH, Vance CP (2003) Legumes: importance and constraints to greater use. Plant Physiol 131:872–877

Grimshaw J, Bayton R (2009) New trees. Recent introductions to cultivation. Royal Botanic Gardens, Kew

Hammer K (1988) Preadaptation and domestication of crops and weeds. Biol Zent 107(6):631–636

Hammer K (1991) Checklists and germplasm collecting. FAO/IBPGR Plant Genet Resour Newsl 85:15–17

Hammer K (1999) Paradigmenwechsel im Bereich der pflanzengenetischen Ressourcen. Vortr Pflanzenzüchtg 46:345–355

Hammer K (2003) Resolving the challenge posed by agrobiodiversity and plant genetic resources—an attempt. JARTS Beih. 76:1–184. Kassel University Press

Hammer K, Khoshbakht K (in prep.) The Big Five. A domestication assessment. Tehran

Hammer K, Laghetti G (2006) Small agricultural islands and plant genetic resources—Le piccole isole rurali italiane. Bari

Hammer K, Teklu Y (2008) Plant genetic resources: selected issues from genetic erosion to genetic engineering. J Agric Rural Dev Trop Subtrop 109:15–50

Hammer K, Heller J, Engels J (2001) Monographs on underutilized and neglected crops. Genet Resour Crop Evol 48:3–5

Hammer K, Gebauer J, Al Khanjari S, Buerkert A (2009) Oman at the crossroads of inter-regional exchange of cultivated plants. Genet Resour Crop Evol 56:547–560

Hanelt P, IPK (eds) (2001) Mansfeld's encyclopedia of agricultural and horticultural crops, vol 1. Springer, Berlin, p 6

Harlan JR (1967) A wild wheat harvest in Turkey. Archaeology 20:197–201

Hermann M, Heller J (eds) (1997) Andean roots and tubers: ahipa, arracacha, maca and yacon. IPGGRI, IPK, Rome, Gatersleben

Heywood VH, Brummitt RK, Culham H, Seberg O (2007) Flowering plant families of the world. Royal Botanical Gardens, Kew

Hobhouse H (1999) Seeds of change: six plants that transformed mankind. Macmillan, London

Isaacs J (1997) Bush food: aboriginal food and herbal medicine. The Rocks, New South Wales

Jansen PCM, Cardon D (eds) (2005) Plant resources of tropical Africa 3. Dyes and tannins, Wageningen

Keller J (2001) Orchidaceae. In: Hanelt P, IPK (eds), Mansfeld's encyclopedia of agricultural and horticultural crops, vol 5. Springer, Berlin, pp 2303–2316

Kellogg EA (2000) The grasses: a case study in macroevolution. Ann Rev Ecol Syst 31:217–238

Khoshbakht K, Hammer K (2008a) How many plant species are cultivated? Genet Resour Crop Evol 55:925–928

Khoshbakht K, Hammer K (2008b) Species richness in relation to the presence of crop plants in families of higher plants. JARTS 109:181–190

Khoshbakht K, Hammer K (2010) Threatened crop species diversity. Shahid Beheshti University Press, Tehran

Kirschner J, Štepánek J, Černý T, de Heer P, van Dijk PJ (2013) Available ex situ germplasm of the potential rubber crop *Taraxacum koksaghyz* belongs to a poor rubber producer, *T. brevicorniculatum* (Compositae-Crepidinae). Genet Resour Crop Evol 60:455–471

Kubitzki K (ed) (2007) Flowering plants. Eudicots. The families and genera of vascular plants, vol 9. Springer, Berlin

Ladizinsky G (1987) Pulse domestication before cultivation. Econ Bot 41:60–65

Laghetti G (2009) Microevolution of *Scolymus hispanicus* L. (Compositae) in south Italy: from gathering of wild plants to some attempts of cultivation. In: Buerkert A, Gebauer J (eds) Agrobiodiversity and genetic erosion, contributions in honor of Prof. Dr. Karl Hammer. Supplement no. 92 to the Journal of Agriculture and Rural Development in the Tropics and Subtropics, Kassel University Press GmbH, pp 119–126

Lawler LJ (1984) Ethnobotany of the Orchidaceae. In: Arditti J (ed) Orchid biology: reviews and perspectives, vol 3. Comstock Publishing Associates, Ithaca, pp 27–194

Laws B (2010) Fifty plants that changed the course of history. Quid Publishers

Lemmens RHJM, Bunyapraphatsara N (eds) (2003) Plant resources of South-East Asia 12, medicinal and poisonous plants, vol 3. Leiden, The Netherlands

Lev-Yafun S, Abbo S (1999) Traditional use of A'kub (*Gundelia tournefortii*, Asteraceae), in Israel and the Palestinian authority area. Econ Bot 53:217–223

Lewis G, Schrire B, Mackinder B, Lock M (eds) (2005) Legumes of the world. The Royal Botanic Gardens, Kew

Li Ch-Y, Zang G-Y, Hammer K, Yang Ch-Y, Long Ch-L (2011) A checklist of the cultivated plants of Yunnan (PR China). Genet Resour Crop Evol 58:153–164 + electronic appendix

Linder HP, Rudall PJ (2005) Evolutionary history of Poales. Ann Rev Ecol Syst 36:107–124

Lips E (1956) Die Reisernte der Ojibwa-Indianer. Wirtschaft und Recht eines Erntevolkes. Akademie-Verlag, Berlin

Logan HH, Dixon AR (1994) Agriculture and the acquisition of medicinal plant knowledge. In: Etkin NL (ed) Eating on the wild side. University Arizona Press, Tucson, pp 25–45

Mabberley DJ (2008) Mabberley's plant book, 3rd edn. Cambridge University Press, Cambridge

Marshall E (2001) Agriculture and use of wild and weedy greens by the PiiK ap Oom Okiek of Kenya. Econ Bot 55:32–46

Maurizio A (1927) Die Geschichte unserer Pflanzennahrung. Paul Parey, Berlin

Moreno-Black G et al (1996) Non-domesticated food resources in the marketplace and marketing system of Northeastern Thailand. J Ethnobiol 16:99–117

Natho G (2001) Rubiaceae. In: Hanelt P, IPK (eds), Mansfeld's encyclopedia. Springer, Berlin, pp 1764–1789

Nayar NM (2011) Agrobiodiversity in a biodiversity hotspot: Kerala State, India. Its origin and status. Genet Resour Crop Evol 58:55–82

Pandey A, Nayar ER, Venkateswaran K, Bhandari BC (2008) Genetic resources of *Prunus* (Rosaceae) in India. Genet Resour Crop Evol 55:91–104

Pickersgill B (2009) Domestication of plants revisited—Darwin to the present day. Bot J Linn Soc 161:203–212

Pickersgill B, Lock JM (eds) (1996) Advances in legume systematics 8. Legumes of economic importance. Royal Botanic Gardens, Kew

Pistrick K (2003) Mansfeld's encyclopedia of agricultural and horticultural crops and the Mansfeld phenomenon. Schr Genet Resour 22:21–31

Prendergast M (1999) Uncommon grounds. In: The history of coffee and how it transformed our world. Basic Books, New York

Purugganan MD, Fuller DQ (2009) The nature of selection during plant domestication. Nature 457:843–848

Ram G, Bhan MK, Ahuja A, Meena SR, Kaul MK, Gupta KK, Jolly RL, Khajuria RK (2007) Variability and selection on different *Argyrolobium roseum* accessions for morphological traits and yield. Genet Resour Crop Evol 54:649–654

Roberts JA, Beale CR, Bensler JC, McGough HN, Zappl DC (1995–2002) CITES orchid checklist I–III. Richmond, Royal Botanic Gardens, Kew

Simpson BB (2009) Economic importance of Compositae. In: Funk VA, Susanna A, Stuessy TF, Bayer RJ (eds) Systematics, evolution and biogeography of Compositae. IAPT, Vienna, pp 45–58

Sprent JI, McKey D (eds) (1994) Advances in legume systematics 5. The nitrogen factor. Royal Botanic Gardens, Kew

Stebbins GL (1981) Coevolution of grasses and herbivores. Ann Mo Bot Gard 68:75–86

Tilman D (1999) Global environmental impacts of agricultural expansion. The need for sustainable and efficient practices. PNAS USA 96:5995–6000

van Beilen JB, Poirier Y (2007) Establishment of new crops for the production of natural rubber. Trends Biotechnol 25:522–529

Vaughan DA, Balázs E, Heslop-Harrison JS (2007) From domestication to super-domestication. Ann Bot 100:893–901

Westphal E, Jansen PCM (eds) (1989) Plant resources of South-East Asia. A selection. Pudoc, Wageningen

Zeder MA, Emshwiller E, Smith BD, Bradley DG (2006) Documenting domestication. In: Zeder MA, Emshwiller E, Smith BD, Bradley DG (eds) A critical examination of markers of initial domestication in goats (*Capra hircus*). University of California Press, Berkeley, pp 181–208

Zeven AC, de Wet JMJ (1982) Dictionary of cultivated plants and their regions of diversity. Wageningen

Zohary D (1999) Monophyletic vs. polyphyletic origin of the crops on which agriculture was founded in the Near East. Genet Resour Crop Evol 46:133–142

Zohary D (2004) Unconscious selection and the evolution of domesticated plants. Econ Bot 58:5–10