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The wild and the grown – remarks on *Brassica*

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ABSTRACT

Brassica is a genus of the Cruciferae (Brassicaceae). The wild races are concentrated in the Mediterranean area with one species in CE Africa (Brassica somaliensis Hedge et A. Miller) and several weedy races reaching E Asia. Amphidiploid evolution is characteristic for the genus. The diploid species Brassica nigra (L.) Koch (n = 8), Brassica rapa L. emend. Metzg. (n = 10, syn.: B. campestris L.) and Brassica oleracea L. (n = 9) all show a rich variation under domestication. From the naturally occurring amphidiploids Brassica juncea (L.) Czern. (n = 18), Brassica napus L. emend. Metzg. (n = 19) and the rare Brassica carinata A. Braun (n = 17) also some vegetable races have developed. The man-made Brassica ×harmsiana O.E. Schulz (Brassica oleracea × Brassica rapa, n = 29, n = 39), or similar hybrids, serve also for the development of new vegetables. Brassica tournefortii Gouan (n = 10) from another Brassica-cytodeme, different from the Brassica rapa group, is occasionally grown as a vegetable in India. Brassica has developed two hotspots under cultivation, in the Mediterranean area and in E Asia.

Cultivation by man has changed the different Brassica species in a characteristic way. The large amount of morphologic variation, which exceeded in many cases variations occurring in distinct wild species, has been observed by the classical botanists by adding these variations to their natural species by using Greek letters. Later taxonomists used the category botanical variety (var.). In this way impressive systems have been established, e.g. for Brassica oleracea. Later on, the other species followed. The variation from E Asia, particularly in the species Brassica rapa and Brassica juncea, was much later included into the investigations, simply because of lacking information. However, this material was included, in the last one hundred years, in classifications according to the International Code of Botanical Nomenclature, ICBN (McNeill et al. 2006). An overview is provided of the infraspecific taxa in Brassica vegetable species. This is one possibility to demonstrate the rich variation of the cultivated races. Included here are our experiences with field studies in the Mediterranean area (especially Italy) and E Asia (Korea, China). A short discussion is devoted to the classification of material according to the International Code of Nomenclature for Cultivated Plants, ICNCP (Brickell et al. 2009). Reducing the possibilities for classification largely to cultivars and cultivar groups, this Code is certainly adapted to modern agri- and horticulture, including the seed business.

Whereas cultivated plants experience a fast evolution, depending on the speed of breeding progress in different periods of the last less than 10.000 years, starting from the so called Neolithic revolution, wild plants are following usually slower evolutionary pathways over a much longer time span. It is difficult to classify wild and cultivated plants under the same system. The genus Brassica provides material, also showing a complex reticulate evolution difficult to classify, which can help developing ways for a general framework.

***Keywords*:** Brassica spp., vegetable, classification, genetic resources, wild plants, weedy plants, cultivated plants

INTRODUCTION

Brassica is widely distributed in the Mediterranean with about 20 species. The scope of the genus is still under discussion, with some researchers including into Brassica also Sinapis L. (with S. alba L. [Brassica hirta Moench], an important oil seed plant and also vegetable in the Mediterranean and the farmweed S. arvensis L. [Brassica kaber (DC.) Wheeler], see Baillargeon 1986). Also other genera show close relationships as evidenced also by crossing experiments. The genus Raphanus L. has produced hybrids with Brassica of some economic importance (×Brassicoraphanus Sageret, syn. ×Raphanobrassica Karpechenko, see Specht 2001). The genus Raphanus is possibly derived from B. nigra and B. rapa/oleracea hybrids (Mabberley 2008). Eruca Mill. is another close relative and possible candidate for inclusion (Pignone and Gómez Campo 2010). Modern taxonomists speak about the Diplotaxis-Erucastrum-Brassica complex (Sánchez-Yélamo 2009).

The free crossability of closely related wild/weedy/ and cultivated races sharing the same genome led to proposals for lumping, e.g. for the Brassica oleracea group (Gladis and Hammer 2001), with reduction on the number of species.

Some species of Brassica (e.g. *B. rapa*, Zohary et al. 2012) have been early in history used for their seeds as an oil crop. Today, the development of some Brassica species towards a crop for edible and industrial oils uses has reached a great importance (Daun et al. 2011). They are the third most important source of vegetable oils after oil palm and soybean (Gupta and Pratap 2007). Oilseed brassicas have been recently treated in more detail (Diederichsen and McVetty 2011). Therefore, only some results are summarized in this introduction. Oilseed brassicas include Brassica carinata (cultivated in Ethiopia and North-east Africa), B. napus (cultivated in Europe and North America) and B. juncea (mainly cultivated in South- and South-east Asia). They are amphidiploids combining genomes of the diploid species B. rapa , B. nigra and B. oleracea as already found out by U (U 1935) who is well known for the triangle of U. Several Brassica oil seeds, including B. carinata, B. juncea , B. napus and the diploid B. rapa, naturally produce seed oil moderate to high in erucic acid ($22{:}1^{cis\Delta13}$) content and moderate to high protein content in the seed meal after oil extraction (Downey and Röbbelen 1989). Ranges of erucic acid content in these species have been reported by Velasco et al. (1998) as: B. carinata: 29.6-51.0%; B. juncea: 15.5-52.3%; B. napus: 5.6-58.1% and B. rapa: 6.5-61.5%. Black mustard and kale also naturally produce seed oil with a range in erucic acid content. Tahoun et al. (1999) have reported erucic acid content ranges for B. nigra: 30.3-45.0% and for B. oleracea: 0.1-62.0%. The plants and seeds of all Brassica oilseeds contain glucosinolates, secondary metabolites which serve as chemical protectants (Mitten 1992). Ranges of glucosinolate content in these species have been reported to be 20 to > 200 µmol g^{-1} seed total glucosinolates for B. napus, B. oleracea and B. rapa; 75 to > 150 µmol g^{-1} seed total glucosinolates for B. carinata and B. nigra and 100 to > 200 µmol g^{-1} seed total glucosinolates for B. juncea (Röbbelen and Theis 1980).

Different Brassica oilseeds species predominate in different regions of the world. In the warmer semi-tropical regions, B. juncea and B. rapa predominate while in cooler temperate regions B. napus and B. rapa. B. carinata is limited to Ethiopia and northeast Africa, while B. nigra is grown in Europe and Asia. B. nigra is currently grown mainly as a condiment crop. B. oleracea is exclusively a vegetable crop produced globally. B. juncea is an important oilseed species in Asia and also an important condiment crop in Canada that has recently been converted to a new Canadian edible oilseed crop (Potts et al., 2003). B. napus is the predominate oilseed species in Australia, Europe, Canada, and China, while B. juncea is the predominate species in India and northwest China. Winter B. napus types are grown in southern Europe while spring B. napus and B. rapa types are grown in northern Europe (Gupta and Pratap, 2009). Winter B. rapa types, formerly grown in northern Europe, have been replaced by higher yielding winter B. napus types. B. tournefortii is cultivated on a small scale in India (Diederichsen 2001).

Here, the vegetable brassicas will be treated in more detail. They include after Diederichsen (2001) Brassica oleracea, B. rapa, B. juncea, B. napus, B. ×harmsiana, B. carinata, and B. nigra. Gladis and Hammer (1990) also mention Brassica tournefortii. There is a high range of different usages, which also include different plant parts (see table 1).

Table 1. Cultivated brassicas in the different usage groups indicating also the plant parts used(after Gladis and Hammer 1990, modified)

Organ / *Brassica* species	1	2	3	4	5	6	7	8
Roots and Hypocotyls	--	--	V	FV	--	--	VF	--
Shoots and Leaves	V	F	GVD	FGV	GFV	VFD	VFGD	V
Leaf buds	--	--	V	V	--	V	V	--
Inflorescences	B	B	BV	BV	B	VB	BV	--
Seeds	OM	O	OMFG	OF	OMG	--	OF	O

1 = *Brassica carinata*, 2 = *B. ×harmsiana*, 3 = *B. juncea*, 4 = *B. napus*, 5 = *B. nigra*,
6 = *B. oleracea*, 7 = *B. rapa*, 8 = *B. tournefortii*
Usage groups (ordered according to their importance): B = bee-fodder, G = green manuring, F = fodder, V = vegetable, O = oilseed, M = medicinal and spice plant, D = decorative and ornamental plant, -- = not known

There are experiences from field studies of the authors of this paper from the primary centre of variation of Brassica in the Mediterranean area, especially from Italy (Hammer et al. 1992, 1999, 2011) and in E Asia (Hoang et al. 1997, Hammer et al. 2007, Li et al. 2011). During several collecting missions, which are documented in the compilations cited above, emphasis was laid on cultivated plants, crop wild relatives (Maxted et al. 2008) played an important role from early phases of our exploration (e.g. Perrino et al. 1992).

As many Brassica spp. contain cultivated, wild and weedy races, insights into evolutionary pathways were possible within this genus of traditional vegetable crops, which surely belong to the oldest crop plants. Elements of human behavior should be included in this survey. Together with botanical, genetical and horticultural elements, a broad scope of information has to be included. The book of Ambrosoli (1997), who studied the fodder plants, relatively new crops with first origins in the classical world and a later development in N Italy and W Europe (1350 – 1850). Their botany and agriculture, has been taken as a model for our treatment, as can be seen also from the title of our paper.

MORPHOLOGICAL DIVERSITY OF BRASSICA SPECIES

A brief overview over morphologically based classifications of cultivated Brassica vegetable species and their wild relatives is provided here. The most important species are treated, including also the races used as oil crops. A wide range of geographic distribution and a tremendous range of different usages lead to an enormous phenotypic range of diversity in Brassica. Homologous developments for usages and organs used occurred in different species (see table 1). As for several usage groups and crop types, common names are not available in English, we prefer the Latin names according to ICBN (McNeill et al. 2006). Naming according to the ICNCP (Brickell et al. 2009) is not preferable in Brassica because of the limited possibilities for infraspecific classification (only cultivar and cultivar groups), which may be sufficient for growers and seed business, but not for researchers engaged in taxonomy and evolution. The lacking of handling of landraces according to ICNCP has already criticized by Pickersgill and Karamura (1999). Another change in the development of the ICNCP is the removing of the very useful category of convar. (cultivar group is no substitute), which has been proposed by Alefeld (1866, see also Landsrath and Hammer 2007) and was advocated e.g. by Mansfeld (1959). In the first issues of ICNCP it can still be found. Fortunately we can rely on ICBN and its infraspecific possibilities (except convar. which was under ICNCP). In Brassica since Linnaeus (1753, 1763) a formal infraspecific classification has been created and further developed by De Candolle (1824), Alefeld (Alefeld 1866) and others. Formal classification proved to be useful in monitoring the decline of diversity in agriculture (Vellvé 1993, Hammer et al. 1996). Contrary to the trend to use informal classifications (Toxopeus and Oost 1985, see Hanelt 1986 b), for an example see table 2), formal classifications for Brassica are still in predominant use (some recent examples are: Louarn et al. 2007, Qi et al. 2008, van Treuren and Bas 2008, Wu et al. 2009, Cleemput and Becker 2012, Girke et al. 2012).

Table 2. Examples comparing informal and formal classification of *Brassica rapa* (after Diederichsen 2001, modified)

Utilized plant organ(s)	Informal group	Formal classification
Root	Vegetable turnip group	ssp. *rapa*
Root	Fodder turnip group	ssp. *rapa*
Root and Leaf	Leaf turnip	ssp. *chinensis* var. *chinensis*
Leaf	Chinese cabbage	ssp. *pekinensis* var. *glabra*
Leaf	Pak Choi and Saishin	ssp. *chinensis* var. *chinensis* et var. *purpuraria*
Leaf	Taatsai	ssp. *chinensis* var. *rosularis*
Leaf	Mizuna	ssp. *nipposinica*
Inflorescence and young leaves	Broccoletto	ssp. *oleifera* var. *ruvo*
Seed	Winter turnip rape	ssp. *oleifera* var. *oleifera* f. *autumnalis*
Seed	Spring turnip rape	ssp. *oleifera* var. *oleifera* f. *praecox*
Seed	Brown sarson and toria	ssp. *dichotoma*
Seed	Yellow sarson	ssp. *trilocularis* var. *trilocularis* et var. *quadrivalvis*

Brassica oleracea L.

Brassica oleracea has no distinct race for seed use, but is very rich in diversity for vegetable, forage, ornamental and other uses. The genetic relationships among the cultivated taxa of the genus Brassica were studied by various cytologists in the beginning of the 20 century and in 1935 U summarized the results by presenting what is frequently referred to as U's triangle (U 1935, Helm 1963, Mizushima 1980). U's concept has been extremely fruitful for understanding the evolution of the important Brassica crops and inspired a lot of research and breeding activities in the genus Brassica (Snowdon 2007). One of the diploid species is B. oleracea (n=9) which has been cultivated for a long time. The wild progenitors of the different cultivated B. oleracea races are the perennial subspecies of B. oleracea (as proposed by Gladis and Hammer 2001). Yarnell (1956), Snogerup (1980) and others have proposed that different taxa of this group were involved in the evolution of the various vegetable races of the cultivated taxa of B. oleracea. The closest wild relative is the wild perennial cabbage of the European Atlantic coast, B. oleracea subsp. oleracea (Snogerup et al. 1980, Song et al. 1990, Hodgkin 1995, Gustafsson and Lannér-Herrera 1997). Glucosinolate investigations support a multiphyletic origin for cultivated forms from different races (subspecies) of wild Brassica (Mithen et al. 1987). On the basis of linguistic, literary and historical information, Maggioni et al. (2010) postulated for the origin of cultivated races of Brassica oleracea the ancient Greek speaking areas of the Mediterranean, namely Magna Grecia. Theophrastus (c. 372 – 287 BC) already described different races of Brassica oleracea, e.g.with curly and smooth leaves (Hondelmann 2002).

Brassica oleracea is a good example where wild and cultivated races show clearly differing pathways. The wild races, mainly from the Mediterranean, reached several islands, mainly swimming and thus showing large fruits. They are adapted to calcareous cliffs where they could successfully escape goats and fire. Their populations on less protected grounds have already disappeared long ago and only recently a reduced selection pressure brings them back in the neighbourhood of gardens where introgressions with the cultivated races could be observed (Perrino and Hammer 1985). From the wild races ssp. rupestris, ssp. insularis, ssp. macrocarpa and ssp. villosa formed a cluster, genomically not closely related to the cultivated types (Mei et al. 2010). The wild races of the Brassica oleracea cytodeme can be seen from table 3 .

Cultivated races

ssp. capitatoides Gladis et K. Hammer, nom. prov. The plants are derived from crosses between wild and cultivated B. oleracea. They are usually stabilized crossing products (Snogerup 1980, Gladis and Hammer 2003). Plants mostly semi-cultivated, sometimes wild, forming small populations. The Potuguese “Galega” kales (Dias 1995) may belong here.

ssp. capitata (L.) DC. s.l., here, all cultivated cabbages are included (Gladis and Hammer 2003).

convar. fruticosa (Metzg.) Alef. Most primitive and perennial types with wooden and branched shoots. Only one variety present.

var. ramosa DC. perpetual kale. A primitive variety with ramifications (cottager’s kale). . Leaves used as a cooking vegetable or fodder. This perennial kale today can be found as a relic crop in W Europe (Zeven et al. 1998, Dias 2012) and some tropical areas (Diederichsen 2001).

convar. acephala (DC.) Alef. All not branched vegetable races for leaf use are included here. As already discussed, the category convar. has been excluded from the latest version of ICNCP (Brickell et al. 2009). However, this category is important for variable cultivated plants and, therefore it is maintained here traditionally (see Helm 1960 – 1963).

var. acephala DC. (excl. var. ramosa). Primitive races from southern Italy may belong here (Branca and Iapichino 1997, Branca et al. 2010) and also the above mentioned “Galega” kales.

var. gongylodes L. kohlrabi. Helm (1959) lists three different forms: f. gongylodes (L.) Helm (with green stem tubers), f. violacea Lam. (with violet stem tubers), f. dissecta Peterm.(with laciniate leaves). A similar race was described by A.P. De Candolle as ß crispa DC., Syst. Nat. 2 (1821) 586, based on the Italian landrace “Pavonazza” which was grown around Naples (Helm 1963). A similar race was found by us in Apulia (Hammer et al. 1989, fig. 10). Primitive kohlrabis with large tubers (Germ. Strunk-Kohlrabi) are relic crops in some countries, e.g. “kana pchali” in Georgia (Beridze et al. 1983).

Table 3. The wild races of the Brassica oleracea cytodeme

Species	Chromosome Number and caryotype	Infraspecific Classification	Status
Brassica oleracea L.	*n*=9, C	ssp. *oleracea*	Wild
	n=9, C	ssp. *bourgaei* (Webb in Christ) Gladis et K. Hammer	Wild
	n=9, C	ssp. *cretica* (Lam.) Gladis et K. Hammer	Wild
		var. *aegaea* (Heldr. et Hal.) Gladis et K. Hammer	
		var. *cretica* (Lam.) Coss.	
		var. *laconica* (Gust. et Snog.) Gladis et K. Hammer	
		var. *nivea* (Boiss. et Sprun.) Gladis et K. Hammer	
	n=9	ssp. *hilarionis* (Post) Gladis et K. Hammer	Wild
	n=9	ssp. *incana* (Ten.) Gladis et K. Hammer	Wild
		var. *botteri* (Vis.) Gladis et K. Hammer	
		var. *cazzae* (Ginzberger et Teyber) Gladis et K. Hammer	
		var. *incana* (Ten.) Gladis et K. Hammer	
		var. *mollis* (Vis.) Gladis et K. Hammer	
	n=9	ssp. *insularis* (Moris) Rouy et Fouc.	Wild
		var. *angustiloba* Schulz	
		var. *aquellae* Widler et Bouquet	
		var. *atlantica* (Coss.) Batt., Batt. et Trab.	
		var. *conferta* (Jordan) Schulz	
		var. *insularis* (Moris) Coss.	
		var. *latiloba* Schulz	
	n=9	ssp. *macrocarpa* (Guss.) Gladis et K.Hammer	Wild
		var. *drepanensis* (Caruel) Schulz	
		var. *macrocarpa* (Guss.) Gladis et K. Hammer	
	n=9	ssp. *robertiana* (Gay) Gladis et K.Hammer	Wild
	n=9	ssp. *rupestris* (Raf.) Gladis et K.Hammer	Wild
		var. *brevisiliqua* (Raimondo et Mazzola) Gladis et K. Hammer	
		var. *hispida* (Raimondo et Mazzola) Gladis et K. Hammer	
		var. *rupestris* (Raf.) Paol.	
	n=9	ssp. *villosa* (Bivona-Bernardi) Gladis et K.Hammer	Wild
		var. *bivoniana* (Mazzola et Raimondo) Gladis et K. Hammer	
		var. *taurica* (Tzvel.) Gladis et K. Hammer	
		var. *tinei* (Lojac.) Gladis et K. Hammer	
		var. *villosa* (Biv.) Coss.	

For further brassicas and wild/occasionally cultivated relatives see Diederichsen and McVetty 2011

var. medullosa Thell. marrow-stem kale. Mainly used as fodder plant. Possibly originated from a cross of var. gongylodes and var. viridis (Gladis and Hammer 2003). Already mentioned by De Candolle (1824) as “chou moellier”(Helm 1959).
var. palmifolia DC. palm kale. An old race. Today still widely grown as delicious vegetable in Italy (Hammer et al. 1990).
var. sabellica L. curled kitchen kale. Still wide spread as a cooking vegetable with good winter hardiness. Often united with the following variety (e.g. by Helm 1959). Helm (1963) described f. sabellica (L.) Helm (green) and f. rubra Peterm. (purple-violet). Recently, a long-stalked, purple leaved variety of the latter is commonly used as ornamental plant in Germany.
var. selenisia L. feather kale. Formerly a common garden plant, today rather rare. Helm (1963) differentiates f. selenisia Helm with green and f. scotica (Alef.) Helm with purple or partly coloured foliage. Races with feathery and laciniated leaves occur also in other botanical varieties of B. oleracea (vgl. Helm 1962).
var. viridis L. kale, collard. Occasionally grown for fodder, young leaves for human consumption. Helm (1959) describes three races: f. viridis L. (green), f. purpurascens

(DC.) Thell. (red) and f. exaltata (Rchb.) Thell., Jersey kale, the long, lignified stems of which are used for roof constructions and walking sticks (Hew and Rumball 2000). The first two forms are very traditional in Italy. Also relic crop in the US (Farnham et al. 2008).

convar. botrytis (L.) Alef. This group unites all races which are grown for the use of young inflorescenses. "Mugnoli" from S Italy can be seen as a primitive race in this group. The fleshy deformation of the inflorescenses is just developing in this race (Laghetti et al. 2005). This may be a relic of introductions from eastern areas (e.g. Crete) together with Greek (Laghetti et al. 2008) or Albanian (Hammer et al. 2012) immigrants with which the evolution of var. italica and var. botrytis started. In the Salento of Apulia this race can still be found. The glucosinolate profile of "Mugnoli" turned out to be closer to var. italica (Argentieri et al. 2010). Variable material of convar. botrytis was found in Sicily (Branca and Iapichino 1997).

var. italica Plenck. sprouting broccoli. From an Italian speciality it has developed in the last decennia to a world crop. Purple and green heading broccolis are recently placed to this variety. As already stated by Vilmorin (Helm 1959), broccoli is older than cauliflower. As areas of origin Helm (1959) mentioned South Italy, Cyprus and Crete. South Italy is still rich in landraces. Helm (1963) described f. cymosa Duch. (green), f. albida Duch. (white), f. flava Peterm. (yellow) and f. italica (Plenck) Helm (violet).

var. botrytis L. cauliflower. Developed in the Mediterranean region and became a world crop. Related to Brassica oleracea ssp. cretica. The introduction from Crete to South Italy could have happened by immigrants from the Levante (Hammer et al. 2011). Sicily and the Naples area played an important role in the further evolution of cauliflower (Branca and Iapichino 1997). Helm (1963) described f. erytrobotrys (Alef.) Helm (violet), f. phaeusa (Alef.) Helm (brown), f. chlorusa (Alef.) Helm (green), f. theiusa (Alef.) Helm (yellow) and f. botrytis (L.) Helm (White). After centuries with predominant white inflorescences, more and more varieties with coloured heads (yellow, green, purple) can be found on the markets today.

var. alboglabra (Bail.) Sun ex Musil. Chinese kale. Evidently originated in the Mediterranean area. Similar races have been collected in S Italy (Maly et al. 1987) and S Spain (Hammer in Gladis and Hammer 2003). The progenitors probably have been moved along the silk road and reached E Asia several centuries ago. Under the specific selection conditions of China this speciality arose. Crisp and Gray (1984) placed it to the broccolis. Helm (1964) and Larkcom (1987) gave detailed descriptions. A fertile amphidiploid hybrid with Raphanus sativus was produced (Chen and Wu 2008).

convar. capitata (L.) Alef. s.l. This is the group of the common cabbages. They originated in the Mediterranean area and have a wide distribution.

var. capitata L. common cabbage. With different colours and head-forms (Helm 1963). Economically most important race of B. oleracea. Eaten as a vegetable raw or cooked. Conserved for later use by fermentation as sauerkraut. After Helm (1963) with f. subacuta Duch., f. conica Duch. and f. capitata (L.) Helm.

var. sabauda L. savoy cabbage. Derived from a cross of var. capitata and var. palmifolia (Gladis 1995). Eaten as a vegetable cooked and raw, especially in winter. Possibly originated in Italy (Helm 1959). Helm (1963) described f. ovata Duch., f. oblonga (DC.) Peterm. and f. sabauda (L.) Helm. For the classification of the eastern cabbages see also Lizgounova in

Zhukovsky (1933). Vilmorin-Andrieux presented races with laciniated leaves which obviously have not be maintained (Gladis and Hammer 2003).

convar. costata (DC.) Gladis ex Diederichsen

var. costata DC. tronchuda kale. The thickened leaf stalks and leaf ribs, sometimes the leaf blades are used as a cooking vegetable. Formerly grown in western Europe, now mainly in Portugal, Angola and Brazil.

var. helmii Gladis et K. Hammer. Derived from a cross of var. capitata and var. sabellica. Today mostly grown as an ornamental plant (Gladis and Hammer 2003). One old German variety with yellowish-green foliage named 'Mosbacher Winter Hellgrüner Blätterkohl' had been used as vegetable.

convar. gemmifera (DC.) Gladis ex Diederichsen. Races with multiple leaf buds on one stalk.

var. polycephala Thell. (syn. var. delachampii Helm (excl. var. millecapitata (Lév.) Helm; after Thellung with open rosettes of leaves, therefore syn. of var. ramosa!), for nomenclatural details see Helm 1959). A race with few multiple heads. Formerly a common garden plant. Perhaps ancestor of var. gemmifera.

var. gemmifera DC. Brussels sprouts. The axillary sproutlets are used as vegetable. Very successful race. Today distributed all over the world. Possibly derived from var. ramosa DC. in the area of Brussels and distributed from there since about 1785 (Helm 1959). We assume an involvement of convar. acephala and var. sabauda (Gladis and Hammer 2003).

Brassica rapa L. em. Metzg.

In the case of B. rapa (the Brassica campestris cytodeme according to Harberd 1972), primary domestications may have happened in W Asia/ E Mediterranean where the wild progenitor (B. rapa ssp. sylvestris) has (possibly extinct?) its natural distribution (now mostly weedy races, but Andersen et al.(2009) discuss about wild races in parts of N Europe) and East Asia with (only?) weedy types of secondary nature. The result in the areas is predominant seed use and vegetable use, respectively (Sinskaja 1928, Warwick et al. 2008). Chinese cabbages originated in China more than 6.000 years ago. Seed oil types came from northern Europe to China and Korea about 2.000 years ago. Two independent domestication events in Europe (Reiner et al. 1995) and E Asia have been postulated by McGrath and Quiros (1992). According to Takuno et al. (2007) a further domestication in E Asia occurred after introduction of primtive cultivated types from Europe and Central Asia. Later, the diploid Brassica rapa hybridized spontaneously with Brassica oleracea and Brassica nigra in areas where their geographical ranges of distribution under cultivation overlapped resulting in three amphidiploid bastards, B. juncea (n=18), B. carinata (n=17) and B. napus (n=19), that are cultivated species of their own, with occasional weedy derivates. The origin of the Indian races, which are grown as oilseeds, is still under discussion. Possibly ssp. dichotoma and ssp. trilocularis belong to the western Eurasian branch together with ssp. rapa and ssp. oleifera, whereas ssp. chinensis, ssp. pekinensis and ssp. nipposinca form the E Asiatic branch (Diederichsen 2001). Toxopeus and Oost (1985) proposed a grouping into cultivar groups.

ssp. sylvestris (Lam.) Janchen, Janchen et Wendelbg. Wild progenitor, today rare and difficult to find. The common weedy races also belong here (var. sylvestris (Lam.) Briggs).

f. campestris (L.) Bogenhard. Wild and weedy forms, widely distributed but becoming rare with the reduction of oilseed turnip cultivation. Many transitions to the following subspecies.

ssp. oleifera (DC.) Metzg. Oilseed turnip.

var. oleifera DC. Oilseed crop.

f. praecox (DC.) Mansfeld. Spring oilseed turnip.

f. autumnalis (DC.) Mansfeld. Winter oilseed turnip.

var. ruvo (Bailey) comb. prov.(Brassica ruvo Bailey; Yang and Quiros (2010) see relations to ssp. nipposinica). This is a common vegetable e.g. in S Italy (cime di rapa) and in Azerbaijan or Turkey (turp). The young sprouts with the flower buds are eaten as a vegetable. There is rich variation in the area with many different types. Used in the same way as broccoli or cauliflower (Astley et al. 1984, Maly et al. 1987, Gladis and Hammer 1992, Hammer et al. 1999). It is an interesting case for the evolution of inflorescenses as vegetable and should be classified as a botanical variety independently of var. oleifera.

ssp. rapa (incl. ssp. orientalis (Sinsk.) Scheb., ssp. mesopotamica Scheb., ssp. afghanica (Sinsk.) Scheb., ssp. japonica Scheb.). Turnip. Widely grown as a root vegetable. In E Asia also the leaves are eaten, this has been also observed in N Africa (Hammer and Perrino 1985). After Hanelt (1986) the most variable race of Brassica rapa. From Japan also races with laciniated leaves are reported (Kitamura 1950, Shebalina and Sazonova 1985). In China they are known since the first Century of our era (Diederichsen 2002). Alefeld (1866) described the races present in European gardens of his time and mentioned material from E Asia. Many types are already lost in Europe. The same may be true for material from a postulated Central Asian center of diversity (Sinskaja 1969). Šebalina (1968), considering the turnip as a species, classified it into five subspecies and many further infraspecific entities. They are taken as the basis for the present treatment for which provisional names have been proposed for better comparison and to fit into the general treatment of Brassica rapa.

convar. rapa (incl. convar. rossica (Sinsk.) Scheb., convar. europaea Scheb.). Variable European group. Today often a relic crop.

var. rapa. With grey and black tubers. A typical relic crop in Central Europe is e.g. the ‘Bayerische Rübe’(Reiner et al. 2005).

var. teltoviensis Alef. Another relic crop in western and central Europe with small tubers, e.g. ‘Teltower Rübchen’ (Landsrath and Hammer 2007).

var. septiceps Bailey. Seven-top turnip or Italian kale. The well developed turnips are usually not eaten but the young sprouts, similar to var. ruvo. This turnip comes from Italy and has a restricted growing area in the United States, Canada and Japan. Placed here in spite of tubers not used (Šebalina and Sazonova 1985).

var. rossica Scheb. Relic crop in parts of Eastern to Western Europe.

var. rubra (Sinsk.) Scheb. Red tubers, in eastern and northern parts of Europe.

var. europaea Scheb. Turnip with white tubers, still wide-spread in Europe.

var. flava (Sinsk.) Scheb. Turnip with yellow tubers, wide-spread in Europe and beyond (e.g. New Zealand).

convar. orientalis (Sinsk.) comb. prov. (B. campestris var. orientalis Sinsk.). Group with small tubers from Turkey and the Middle East (Šebalina and Sazonova 1985).

var. orientalis (Sinsk.) comb. prov. Only one botanical variety.

convar. mesopotamica (Scheb.) comb. prov. (B. rapa ssp. mesopotamica Scheb.), Group from Irak.

var. mesopotamica Scheb. Turnips with green head.

var. violascens Scheb. Turnips outside violet, inside white.

convar. afghanica (Sinsk.) Scheb., incl. convar. chinensis Scheb., convar. indica (Sinsk.) Scheb., convar. ferganica (Sinsk.)

Scheb., convar. sinensis (Sinsk.) Scheb. Variable group from Afghanistan, N India, Uzbekistan, Kirgizstan and W China, only in rare cases known outside this area.

var. afghanica (Sinsk.) Scheb. From Afghanistan and Uzbekistan.

var. indica (Sinsk.) Scheb. The characteristic seed color is yellow brown, going to be diplaced by varieties from the West (Šebalina and Sazonova 1985).

var. hybrida Scheb. Variety with variable characters.

var. ferganica Scheb. Turnips from Uzbekistan and Kirgizstan.

var. sinensis (Sinsk.) comb. prov. (B. campestris var. sinensis Sinsk.). Turnips from W China.

convar. japonica (Scheb.) comb. prov. (B. rapa ssp. japonica Scheb., B. rapoasiatica ssp. japonica Sinsk., nom. illeg., B. rapa ssp. japonica (Sinsk.) Scheb., comb. inval.). Group from Japan and E China.

var. japonica Scheb. Japan, also known in the Western World (Šebalina and Sazonova 1985).

var. alborosea Scheb.

var. intermedia Scheb.

ssp. chinensis (L.) Hanelt (incl. ssp. narinosa (Bailey) Hanelt) pak-choi, Chinese mustard. There have been several attempts to describe the variation of this subspecies (Tsen and Lee 1942, Helm 1963 b, Lee 1982, Gladis and Hammer 1992). However, there is still no generally excepted infra-subspecific system. Typical crop from E Asia. Important races are:

var. chinensis (Juslen.) Kitam. This race is the most typical one.

var. communis Tsen et Lee. For tradional conservation the leaves are dried or salted. Occasionally tuberous roots are formed. There are reports about the consumption of young sprout. There are other variations which are in need of additional studies.

var. parachinensis (Bailey) comb. prov. (B. chinensis var. parachinensis (Bailey) Sinsk.) Helm (1963 b) summarizes the differential characters from the first variety, which are not considered as sufficient (Gladis and Hammer 1992). But they can be taken as a working basis.

var. rosularis (Tsen et Lee em. Lee) Hanelt. Already Lee (1982) included B. narinosa here. For further discussions see Sun (1946) and Lin (1980).

var. dubiosa (Bailey) comb. prov. Described by Bailey (1922, 1930) from China (district of Nanjing). Similar to var. rosularis and also to var. albiflora (Gladis and Hammer 1992).

ssp. pekinensis (Lour.) Hanelt. Pe-tsai, Chinese cabbage. Cultivated in China since more than 500 years (Bretschneider 1898). A head-forming race with a tendency for wider distribution in the last 100 years (Hanelt 1986a).

var. pandurata (Sun) Gladis. Fruit- and seed-characters show a relation to Indian material (Gladis and Hammer 1992).

var. laxa (Tsen et Lee) Hanelt. With loose heads.

var. glabra E. Regel (B. chinensis var. pekinensis (Lour.) Sun). There are different head forms which are formally described as varieties of B. pekinensis (Helm 1961). Sun (1946) as well as Gladis and Hammer (1992) recommend no further splitting. It might be done on the level of forms within var. glabra as follows:

f. laxa (Tsen et Lee) comb. prov. with upright, loose heads

f. pekinensis (Helm) comb. prov., with compact round or elongated heads, and

f.. cylindrica (Tsen et Lee) comb. prov. This highly domesticated race, which has been developed from var. glabra, experienced a wide distribution in Europe and America.

ssp. nipposinica (Bailey) Hanelt. A vegetable crop from E. Asia with rather variable leaf characters (simple and laciniate leaves).

var. perviridis Bailey. (ssp. perviridis Bailey). Tendergreen, spinach mustard. Cultivated as a leaf vegetable and also for the tuberous roots. Introduced in the first half of the last century to SE United States. Related to B. chinensis var. utilis Tsen et Lee (1942), see under ssp. trilocularis.
var. lorifolia Bailey. The tuberous roots are used. Possibly related to var. chinoleifera (Gladis and Hammer 1992).
var. dissecta (Schulz) Gladis. All races with dissected leaves (Makino 1912) belonging to ssp. nipposinica are placed here.
ssp. trilocularis (Roxb.) Hanelt. Oilseed crop, only occasionally vegetable. Mainly used in India.
var. trilocularis (Roxb.) Duthie et Fuller. Variable oilseed crop, showing some crossing barriers to other subspecies of the species (Olsson 1954). Yellow sarson is self-compatible. Very old oilseed crop, already mentioned in Sanskrit documents from 1500 BC. (Diederichsen 2001). Fruit with 3 and 2 valves.
var. quadrivalvis (Roxb.) Duthie et Fuller. The only known cruciferous crop with 4-valved fruit, sometimes containing a second small fruit within the basal siliques. The vernacular name yellow sarson is also applied to this variety.
var. chinoleifera (Viehoever) Kitam. (var. utilis Tsen et Lee). Variable oilseed crop from China, especially in leaf- and seed-colour (Tsen et Lee 1942). By Gladis and Hammer (1992) placed under ssp. nipposinica. But clearly similar to the Indian ssp. trilocularis.
ssp. dichotoma (Roxb.) Hanelt. Brown sarson, toria. The most traditional oilseed crop of India. Toria is close to ssp. oleifera (Olsson 1954). Disappearing or already disappeared from cultivation.
Brassica nigra (L.) Koch
Black mustard is mostly cultivated as an oilseed crop, for the production of mustard, occasionally grown as a vegetable (Ethiopia). The B genome turned out to be relatively conservative (Liu and Wang 2006). Brassica nigra is an ancient crop plant with interesting resistance characters (Sheng et al. 2012). Sinskaja (1928) differentiates between a Western and a Eastern group, which can be accepted as subspecies. In Italy formerly frequently cultivated (Maly et al. 1987), now mostly a weed (Aeschimann et al. 2004). A third group from India (var. indica Sinsk.) is not yet sufficiently known (Gladis and Hammer 1992).
ssp. nigra. Western group. Cultivated in Europe, Ethiopia, Afghanistan, Crete and Cyprus.
var. nigra (incl. var. torulosa (Pers.) Alef., var. turgida (Pers.) Alef.). Also common ruderal and segetal plant.
var. pseudocampestris Sinsk. Segetal plant adapted to Brassica rapa ssp. oleifera. Today very rare because of the decline of B. rapa ssp. oleifera cultivation.
var. abyssinica A. Braun. Cultivated and weedy in Ethiopia.
ssp. hispida (Schulz) Gladis. Eastern group. Cultivated in Syria, Israel, Thessalia and Asia Minor.
var. rigida Sinsk. High growing plants from Syria, Israel and Thessalia.
var. orientalis Sinsk. Low growing plants from Asia Minor.
Brassica tournefortii Gouan
Cultivated on a small scale in NW India and W Tibet as an oilcrop. The chromosome number is n = 10, but cytogentically different from Brassica rapa (n = 10).
Brassica carinata A. Braun
Abyssian mustard is grown as a oilseed crop and also as a leaf vegetable in Ethiopia, Kenia and some other E African countries (Alemayehu and Becker 2002). Today also as a new crop in Europe and America (Warwick et al. 2006). The variation of this crop is not very high. As the two parental species B. oleracea and B. nigra possibly

have been introduced to Ethiopia with Amharic agricultural tribes in the first millennium BC, B. carinata could have its origin here and was later distributed to other African areas. In Italy in trials as an alternative oil crop for biodiesel production (Cardone et al. 2003).

Brassica napus L. This allopolyploid hybrid (x = 19) with genomes from Brassica rapa and B. oleracea (Hu et al. 2011) evidently originated under domestication. As place of origin N Africa has been proposed, were "truly wild" material was found (Fiori 1923-25). Brassica napus is considered as a relatively young crop that originated in limited geographical region (Kimber and McGregor 1995). There are differences in the genetic background between Eastern and European genotypes (Zhou et al. 2006). Natural crosses between the two parental species have been observed (Hansen et al. 2001). Subspecies napus is mainly grown as an oilseed crop and became a world crop in the last century (Diederichsen and McVetty 2011). Subsp. rapifera is mainly a root vegetable.

ssp. rapifera Metzg.(ssp. napobrassica (L.) Hanelt). Swede, Swedish turnip, rutabaga. Formerly concentrated on Europe, especially N Europe and Russia, today also in many other areas as the United States, Siberia and Far East. A separate origin from ssp. napus has been proposed (Diederichsen 2001). In the classification of swede we follow Šebalina and Sazonova (1985).

var. rapifera Metzg. European races. Alefeld (1866) described a number of varieties. The N European history has been stressed by Ahokas (2002). A possible origin is in the Mediterranean area, where both progenitors co-existed (Hanelt 1986 a). Many cultivars.

var. rossica Sinsk. Russia to Finland.

var. sibirica (Scheb.) Bondar. et Pivovar. Yellow swede from Siberia.

var. schebalinae Bondar. et Pivovar. White swede from Siberia.

ssp. napus. Mostly oilsed crop and fodder plant, one race is grown as a vegetable. First reliable reports in herbals from the 16th and 17th centuries (Diederichsen 2001). Possibly originated in the W Mediterranean area. Wild (weedy?) plants have been reported from N Africa (Fiori 1923/25).

var. napus. Rape, canola. Very common as an oilseed crop in many parts of the world, recently also in E Asia (see Diederichsen and McVetty 2011).

f. annua (Schübl. et Mart.) Thell. Summer rape.

f. biennis (Schübl. et Mart.) Thell. Winter rape.

var. pabularia (DC.) Reichenb. Leaf rape, Siberian kale. A variable leaf vegetable.

In addition to the described diversity, there have been done several artificial recombinations of this amphidiploid from different (con-)varieties of the progenitor species, e.g.

B.-×-napus-cauliflower and broccoli developed from B. oleracea convar. botrytis + B. rapa var. ruvo, and

B.-×-napus-cabbage developed from B. oleracea var. capitata + B. rapa var. glabra (namend Hakuran) and others (see Clauss 1975, Yamagishi and Takayanagi 1982).. Today, hakuran is available in the market as vegetable crop. The formal classification of the resynthesis rape vegetables is missing yet.

Brassica juncea (L.) Czern. This alloploid species derived from Brassica rapa and B. nigra. Archaelogical remains from 2.000 BC have been found in the Indus valley (Diederichsen 2001). The Middle East is most likely the area of origin, where both of the original species occur. The largest variation of B. juncea today is found in W and Central China (Huangfu et al. 2009) and Central Asia (Rabbani et al. 1998). Informally they are called root mustard, stem mustard, leafy mustard, stalk mustard and seed mustard (Fu et al. 2006).

Vegetable types originated earlier than oil types, but there is no conclusion concerning the development of oil seed types from vegetable types (Wu et al. 2009). The infraspecific variation has been classified by Bailey 1922, Sinskaja 1928, Sabnis and Phatak 1935, Tsen and Lee 1942, Helm 1959, Nishi in Tsunoda et al. 1980, Chen 1982. We follow here mainly the treatment of Gladis and Hammer (1992), which has been also accepted by Diederichsen (2001). Brassica juncea includes vegetables and oilseed crops. Formerly Brassica cernua (Poir.) Fourb. et Hemsl. was considered as a separate species containing the oilseed brassicas.

ssp. napiformis (Paill. et Bois.) Gladis. The root tubers are used as vegetable. Several races have been described (var. megarrhiza Tsen et Lee (Fu et al. 2006), var. napiformis (Paill. et Bois.) Kitam., var. multisecta Baranov), but despite of additional material from Korea, which could be studied (Kim et al. 1987), the high variation found in still limited material does not allow for deeper insights. Interesting figures of several types have been provided by Qi et al. (2007). This group is urgently in need for a revision.

ssp. tsatsai (Mao) Gladis. Group with fleshy stalks used as vegetable mainly from Sichuan.

var. multiceps Tsen et Lee. Many fleshy short stalks. Possibly related to var. gemmifera Lin et Lee (Lin and Lee 1985).

var. urophylla Tsen et Lee. Described from China (Tsen and Lee 1942) and similar to var. multiceps. Collected by Hammer 1986 in Cuba as a ruderal plant, in an area, where Chinese immigrants played a role as horticulturalists (Hammer et al. 1992 – 1994).

var. linearifolia Sun. Plants with reduced leaf blade (Sun 1946, Lee 1982).

var. tsatsai Mao(var. tumida Tsen et Lee). Variable vegetable in Szechuan where more than 11 forms or cultivars occur (Lee 1982).

ssp. integrifolia (West) Thell. A common leaf vegetable in E and SE Asia. In Italy also cultivated as an oil seed (Fu et al. 2006), in rare cases as a leaf vegetable (Branca 2004).

var. subintegrifolia Sinsk. In this group the use of seeds is predominant. Sinskaja (1928) names the following varieties:

var. sareptana Sinsk.
var. subintegrifolia Sinsk.
var. subsareptana Sinsk.
var. subcrispifolia Sinsk.
var. mongolica Sinsk.
var. japonica Bailey
var. multisecta Bailey

var. integrifolia (Stokes) Sinsk. Basal leaves not dissected. Collected by us in Korea (Gladis and Hammer 1992).

var. rugosa Roxb. ex Prain (incl. var. agrestis Prain, var. typica Prain, var. cuneifolia (Roxb.) Prain). Cultivated as leaf vegetable and oil seed.

var. capitata Tsen et Lee ex Lee. Races forming heads are already described by Kumazawa and Abe (1955/56).

var. longidens Bailey (var. strumata Tsen et Lee). Leaves appear unsymmetrical.

var. crispifolia Bailey. Vegetable with curly leaves, sometimes ornamental.

var. celerifolia Tsen et Lee. Doubtfully belongs to this species (Gladis and Hammer 1992, see also Yang-Zheng 1986).

ssp. juncea. Mainly cultivated for the seeds, sometimes as fodder plant.

var. juncea. Important oilsed plant, occasionally grown as a leaf vegetable (Fu et al. 2006) and ornamental plant.

var. brachycapa Thell. (var. lonigpes Tsen et Lee, var. orthocarpa Sun). Oilseed plant and also fodder crop.

Exact determination not yet possible:

var. chirimenna (Makino) Burkill. Oilseed plant.

var. edona Makino. A synonym of var. rugosa?

var. facilifolia Li. The young inflorescenses are used as vegetable.

Brassica ×harmsiana O.E. Schulz

Synthetic alloploid hybrids with one C genome of Brassica oleracea and at least two A genomes of Brassica rapa (Diederichsen 2001). A number of similar synthetic material have been produced for new oil and fodder plants, sometimes for vegetable crops (Frandsen and Winge 1932, Gladis and Hammer 1990). Analogous hybrids with one genome of Brassica rapa and at least two genomes of Brassica oleracea are introduced under the name of Brassica ×napoleracea Chiang in Cruciferae Newsletter 10 (1985) 25.

Comprehensive keys for botanical determinations of the cultivated species and their infraspecific items have been provided by Bailey (1949) and Gladis and Hammer (2003). Gladis and Hammer (1992) also considered the wild and weedy races. Other keys are confined to species (e.g. Šebalina and Sazonova 1985).

WILD AND WEEDY PROGENITORS AND DESCENDENTS

Spontaneous outcrossings resulting in genetic transfer (introgessions) from the cultivated to the wild species and vice versa have been mentioned by many authors (see compilation by Warwick et al. 2009). Such spontaneous gene transfer has received increased attention after the introduction of transgenic cultivars of rapeseed, B. napus var. napus, during the 1990s (Beckie et al. 2006) and included many other crops.

The wild progenitor and the beginnings of domestication are often unclear and still under discussion (see remarks under the different species), because of the lack of archaeological material and the difficulties of its identification. Linguistic and ethnological data can often provide some first indications (Zohary et al. 2012). In Brassica oleracea the wild progenitor found another ecological possibility for surviving on calcareous cliffs close to the sea side, mainly in the Mediterranean area, where it could escape goats and fire (Perrino et al. 1992). But also these wild plants can be derived from cultivated ones as seems to be the case with the Atlantic populations of Brassica oleracea (Maggioni et al. 2010). All the other cultivated species of Brassica chose a different pathway. They escaped in the agricultural areas and became segetal and ruderal plants. The large fields of cultivated plants (mostly for oil crops) but also garden plants as good pollen donors (mostly for vegetable races) provided a great genetic influence on the weedy or ruderal progenitors, changing their genetic constitution. The results are populations closely related to the cultivated races, which are different from the wild progenitor of crops. This behavior of the cultivated races is called “genetic aggression” (Hammer 2003). Ruderal and weedy races of nearly all cultivated Brassica species are widely distributed in the growing areas and can serve as useful genetic resources (see last paragraph).

LANDRACES AND FURTHER EVOLUTIONL

There is a close relationship between the evolution of crops plants and human cultural evolution (Maffi 2001). We still lack a broad approach of this comprehensive interrelation despite the great achievements reached by A. De Candolle (1806 – 1893), Ch. Darwin (1809 – 1882) and N.I. Vavilov (1887 – 1843). At the beginning of scientific plant breeding agri- and horticulture were full of morphologically distinguishable landraces. Their value for ongoing plant breeding was appreciated at a relative early time (Proskowetz and Schindler 1890). The gradual displacement of these landraces by breeding varieties soon ewaked concern of farsighted scientists, but only relatively late the term "genetic erosion" was coined (Bennett 1968). Soon the "plant genetic resources movement" developed (Pistorius 1997). More and more landraces were disappearing despite of great efforts to maintain them ex situ and, in the last twenty years, on farm. Morphological classification of cultivated plants was the primary approach from the time of Linnaeus (1753, 1763). He was aware of variation under human influence and placed cultivated plants together with the wild ones in species, indicating them by Greek letters. This method was maintained for a long time, e.g. by A.P. de Candolle (1822) and Metzger (1833). Alefeld (1866) advocated a similar treatment of wild and cultivated plants. His only concern was the large variation of cultivated plants. He tried to solve this problem by the introduction of a new infraspecific category (later proposed as convar.) for groups of botanical varieties. This system was further elaborated and turned out to be applicable for landraces. In Brassica this system was used by Bailey from the United States (1922 – 1942), the Vavilov school of Russia (e.g. Sinskaja 1928, Šebalina and Sazonova 1987), the Mansfeld school of Gatersleben (Germany) (e.g. Helm 1959 – 1964). The system is still used in historical context, to classify diverse genbank collections, to report about evolutionary trends in cultivated plants, including genetic erosion (e.g. Hammer and Laghetti 2005) and for other research on genetic resources. For plant breeding and plant production it is less adapted, mainly because of the tremendous loss in morphological variation during conscious plant breeding. Several times a schism was proposed, to separate the classifications of wild and cultivated plants, one of the latest efforts is the creation of "cultonomy" vs. "taxonomy" (Hetterscheid and Brandenburg 1995). Accordingly the ICNCP (Brickell et al. 2009) was adapted mainly for the use of breeders and producers, completely neglecting the landraces (Pickersgill and Karamura 1999). We cannot go into details here, but we want to stress the usefulness of infraspecific formal classifications for crop plant taxonomy, evolution and history.

Table 4 shows the high number of infraspecific races in some of the Brassica-species. Some species are characterized by low numbers of infraspecific races, as Brassica carinata. In other cases the low race number may be due to unsufficient knowledge (e.g. Brassica juncea in E Asia). At any rate, infraspecific classifications allow an overview on the available material and their variation in the fields and in collections. They are useful for historic studies and provide a good method for showing gaps in material and areas. Their special usefulness can be seen for the characterization of landraces.

There is a general trend in landraces towards their flourishing in the $19^{th}/20^{th}$ centuries and their fading away at an increasing speed from the second half of the 20^{th} century. The speed of this process is high, but even in developed countries niches can be found in which an evolution of landraces proceeds.

The domestication syndrome (Hammer 1984, 2003, Pickersgill 2009) is further developing. The nature of selection during plant domestication changed (Purugganam and Fuller 2009). Highly domesticated crops, obtained by special plant breeding methods, resulted in high yielding varieties (Gepts 2004, Brown 2010). The concept of super-domestication shows the way from plant breeding to crop engineering (Vaughan et al. 2007). Super-domestication and gigantism can be also observed in Brassica. Giant cabbages have been decribed from Turkey (Zhukovsky 1933) and hybrids of Brassica rapa ssp. pekinensis are highly productive. The amphidiploid Brassica spp. as the world crop Canola (Brassica napus) and many of the newly generated amphidipoids of the Brassica ×harmsiana type show a fixed heterosis and we begin to understand the mechanisms of gene expressions (Osborn et al. 2003). But the primary products perform agronomically very poorly and have to be improved by prebreeding methods (Seyis et al. 2003).

Table 4. Cultivated brassicas and their infraspecific items according to formal classification

Taxa	ssp.	convars	bot. varieties	other races
Brassica oleracea	ssp. *oleracea*		1	
	ssp. *bourgaei*		5	
	ssp. *cretica*		4	
	ssp. *hilarionis*		1	
	ssp. *incana*		4	
	ssp. *insularis*		6	
	ssp. *macrocarpa*		2	
	ssp. *robertiana*		1	
	ssp. *rupestris*		3	
	ssp. *villosa*		4	
	ssp. *capitatoides*		1	
	ssp. *capitata*	6	18	15
Brassica rapa	ssp. *sylvestris*		1	
	ssp. *oleifera*	2	2	
	ssp. *chinensis*		5	
	ssp. *pekinensis*		4	
	ssp. *nipposinica*		3	
	ssp. *trilocularis*		2	
	ssp. *dichotoma*		1	
Brassica nigra	ssp. *nigra*		3	
	ssp. *hispida*		2	
Brassica tournefortii			1	
Brassica carinata	ssp. *rapifera*		4	
	ssp. *napus*		2	2
Brassica juncea	ssp. *napiformis*		3	
	ssp. *tsatsai*		4	11
	ssp. *subintegrifolia*		14	
	ssp. *juncea*		2	

GENETIC RESOURCES

The still available rich material of landraces, wild and weedy races is seen as the basis for further crop evolution in Brassica (table 5,). According to the gene pool concept of Harlan and De Wet (1971) there are three genepools. Genepool three is very much enlarging at present, so that Hammer (1998) and Gepts and Papa (2003) proposed a fourth genepool for the new products of plant transformation and genomics. A new concept considers an enlarged third genepool. The fourth genepool should contain any synthetic strain shown with nucleic acid frequencies, DNA and RNA, that do not occur in nature (Gladis and Hammer 2002).

Genetic exchange is possible among several cultivated and wild taxa of the genus Brassica despite different chromosome numbers. This became recently very important with the possibility of unintended introgressions of GMOs (Beckie et al. 2006). Species that have the same chromosome numbers and readily cross with each other, form a cytodeme (Harberd 1972) or crossing group (first genepool). The term Brassica coenospecies (more or less second genepool) encompasses all species that are capable of exchanging genes with the

Table 5. Summary of important cultivated species of the genus *Brassica* L., their infraspecific diversity and selected common names

Species	Karyotype[1]	Subspecies	Further infraspecific grouping	Usage type	Common name
B. rapa L. em. Metzg.(syn. *B. campestris* L.)	*n*=10, A	ssp. *oleifera* (DC.) Metzg.		Seed oil, forage, green manure	Oilseed turnip, turnip rape, field mustard, canola
	n=10, A	ssp. *oleifera* (DC.) Metzg.		Leaf and inflorescence as vegetable	Cime di rapa (Italian)
	n=10, A	ssp. *trilocularis* (Roxb.) Hanelt		Seed oil, sometimes vegetable	Yellow sarson
	n=10, A	ssp. *dichotoma* (Roxb.) Hanelt		Seed oil, vegetable, forage	Brown sarson, toria (Hindi), Indian rape
	n=10, A	ssp. *rapa*		Root vegetable, forage	Turnip
	n=10, A	ssp. *chinensis* (L.) Hanelt		Leaves and petioles as vegetable	Pak-choi
	n=10, A	ssp. *pekinensis* (Lour.) Hanelt		Leaves and leafy rosettes as vegetable	Pe-tsai, Chinese cabbage
	n=10, A	ssp. *nipposinica* (Bailey) Hanelt		Leaves as vegetable	Mizuna (Japanese)
B. nigra (L.) Koch	*n*=8, B	ssp. *nigra*		Seed oil and condiment, vegetable and forage	Black mustard (western type)
	n=8, B	ssp. *hispida* (Schulz) Gladis		Seed oil and condiment, vegetable and forage	Black mustard (eastern type)
B. oleracea L.	*n*=9, C	ssp. *capitata* (L.) DC.	convar. *acephala* (DC.) Alef. var. *gongylodes* L.	Stem as vegetable	Kohlrabi
	n=9, C	ssp. *capitata* (L.) DC.	convar. *acephala* (DC.) Alef. var. *medullosa* Thell.	Stem as forage	Marrow-stem kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *acephala* (DC.) Alef. var. *palmifolia* DC.	Leaves as vegetable	Palm kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *acephala* (DC.) Alef. var. *sabellica* L.	Curled leaves as vegetable	Curled kitchen kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *acephala* (DC.) Alef. var. *selenisia* L.	Leaves as vegetable	Russian kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *acephala* (DC.) Alef. var. *viridis* L.	Leaves as vegetable or forage	Colewort, collard
	n=9, C	ssp. *capitata* (L.) DC.	convar. *botrytis* (L.) Alef. var. *botrytis* L.	Budding inflorescence as vegetable	Cauliflower
	n=9, C	ssp. *capitata* (L.) DC.	convar. *botrytis* (L.) Alef. var. *italica* Plenck	Budding inflorescence as vegetable	Broccoli
	n=9, C	ssp. *capitata* (L.) DC.	convar. *botrytis* (L.) Alef. var. *alboglabra* (Bail.) Sun	Budding inflorescence as vegetable	Chinese kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *capitata* (L.) Alef. var. capitata L.	Leafy heads as vegetable	Cabbage
	n=9, C	ssp. *capitata* (L.) DC.	convar. *capitata* (L.) var. *sabauda* L.	Leafy heads as vegetable	Savoy cabbage
	n=9, C	ssp. *capitata* (L.) DC.	convar. *costata* (DC.) Gladis var. *costata* DC.	Petioles and leaves as vegetable	Tronchuda kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *costata* (DC.) Gladis var. *helmii* Gladis et Hammer	Ornametal leaf type	Stor ribbekaal (Danish)
	n=9, C	ssp. *capitata* (L.) DC.	convar. *fruticosa* (Metzg.) Alef. var. *ramosa* DC.	Leave vegetable and forage	Branched, vegetative kale
	n=9, C	ssp. *capitata* (L.) DC.	convar. *gemmifera* (DC.) Gladis var. *gemmifera* DC.	Young side buds as vegetable	Brussel's sprouts
	n=9, C	ssp. *capitata* (L.) DC.	convar. *gemmifera* (DC.) Gladis var. *polycephala* Thell.	Leafy, headed side branches as vegetable	Branched cabbage
B. juncea (L.) Czern.	*n*=18, AB	ssp. *juncea*		Seed oil, forage	Indian mustard, oriental mustard, rai (Hindi)
	n=18, AB	ssp. *integrifolia* (West) Thell.		Leaf vegetable	Leaf mustard
	n=18, AB	ssp. *napiformis* (Paill. et Bois) Gladis		Root vegetable	Tuberous-rooted mustard
	n=18, AB	ssp. *tsatsai* Mao		Petioles and leaves as vegetable	Tsatsai
B. napus L.	*n*=19, AC	ssp. *napus* var. *napus*		Seed oil, forage, green manure	Rapeseed, canola
	n=19, AC	ssp. *napus* var. *pabularia* (DC.) Rchb.		Leaf vegetable	Nabicol, rape-kale
	n=19, AC	ssp. *rapifera* Metzg. (ssp. *napobrassica* (L.) Hanelt)		Root vegetable and forage	Swede, rutabaga
B. carinata A. Braun	*n*=17, BC			Seed oil and vegetable use	Abyssinian mustard

[1] Karyotype according to Mizushima (1980).

important cultivated Brassica species (Prakash et al. 1999).

A wide range of species can be employed for crop improvement (third genepool). Prebreeding or germplasm enhancement is employing an always increasing tertiary genepool. But in the breeding programmes the tendency is to stay within the genepool of adapted material (Downey and Rakow 1987, Becker et al. 1999).

The pollination mode of the different Brassica species ranges from self incompatibility to complete self-fertility. Even within species there exist variations among plant types for pollination mode (Gladis and Hammer 1992). As a tendency, the diploid species are obligate outcrossing, while the amphidiploid bastards are self fertile (Downey and Rakow 1987).

Large genebank collections for Brassica germplasm have been assembled in Europe, India and China. For wild species of the genus Brassica an important collection is available in Spain (Gómez-Campo 2005). The World Vegetable Center (AVRDC) in Taiwan maintains Brassica with 1390 Brassica accessions (AVRDC 2009).

Gladis and Hammer (1990, 2003) provided information on techniques for germplasm regeneration and preservation.

The enlarged tertiary genepool includes the related genera Coincya, Diplotaxis, Eruca, Erucastrum, Hirschfeldia, Sinapis, Sinapidendron, Trachystoma, Enarthrocarpus, Raphanus, Moricandia, Pseuderucaria and Rytidocarpus and successful introgressions have been reported (Hu et al. 2009). As already stated in the introduction of this paper, a first recorded successful wide cross resulted in Raphanus sativus × B. oleracea (Sageret 1986).

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