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# Guide to the Wild Germplasm of Brassica and Allied Crops

## Part IV

Centre for Land
and Biological Resources Research

Centre de recherches sur les
terres et les ressources biologiques

Canada

**Cover illustration**
The images represent the Research Branch's objective: to improve the long-term competitiveness of the Canadian agri-food sector through the development and transfer of new technologies.
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*Conception par le Service aux programmes de recherches*

# Guide to the Wild Germplasm of Brassica and Allied Crops

## Part IV
## Wild Species in the Tribe Brassiceae (Cruciferae) as Sources of Agronomic Traits

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**INTRODUCTION TO THE GUIDE:**

The Cruciferae family, which contains about 3500 species and 350 genera, is one of the ten most economically important plant families (Rich 1991). The tribe Brassiceae is one of the 13-19 tribes which have been recognized within the family and is one of the few tribes believed to constitute a natural group (Hedge 1976, Al-Shehbaz 1984, 1985). It is the most important economically and the most distinctive (Gómez-Campo 1980, Al-Shehbaz 1985). It is distinguished on the basis of the presence of conduplicate cotyledons (i.e. the cotyledons are longitudinally folded around the radical) and/or two-segmented fruits (siliques) which contain seeds in one or both segments, and only simple hairs if present (Gómez-Campo 1980, Al-Shehbaz 1985).

Crop brassicas display enormous diversity and are used as a source of oil, vegetables, mustard condiments, and fodder. Those of particular importance in Canada are: *Brassica napus*, *B. rapa*, and *B. juncea* as sources of canola oil, and *B. oleracea* as cole-crops. The genera *Raphanus* and *Sinapis* are also of major importance, the former cultivated for its edible roots and the latter as a source of mustard condiments along with *B. nigra*. Several species have become naturalized weeds in Canada and the United States [eg. *Sinapis arvensis* (wild mustard), *Raphanus raphanistrum* (wild radish), and *B. rapa* (wild rape)], representing both a potential source of germplasm and agricultural problems. In other areas of the world *Crambe* is cultivated as an industrial oil, and the leaves of other genera (eg. *Eruca* and *Diplotaxis*) are eaten as salad greens.

An understanding of the genetic potential of wild relatives of the crop species of *Brassica* and allied genera (members of the Tribe Brassiceae) is critical for the establishment of long-term breeding programs of these crops. In addition, it is clear that many of the wild species in the tribe have potential value as new crops, as sources of industrial oils (*Crambe*, *Eruca*), condiments (*Sinapis alba*), and other diverse products. Wild relatives also possess a number of useful agronomic traits which could be incorporated into breeding programs, including: cytoplasmic and nuclear male sterility; resistance to disease and insect and nematode pests; intermediate $C_3$-$C_4$ photosynthetic activity; and tolerance of cold, salt and drought conditions.

The last comprehensive taxonomic treatment on the tribe was conducted by Schulz (1919, 1923, 1936). The tribe Brassiceae contains approximately 217 species and 51 genera, 25 of which are monotypic (Table below). Geographically, it is centered in the southwestern Mediterranean region, particularly Algeria, Morocco and Spain, where *c.* 41 genera are either endemic or exhibit maximum diversity. The tribal range extends eastward into India and Pakistan and southward into South Africa, with a poor representation in the New World (Hedge 1976, Gómez-Campo 1980, Al-Shehbaz 1985).

**GENERA OF THE TRIBE BRASSICEAE** (no. species in brackets)

| | |
|---|---|
| Ammosperma (2) | Guiraoa (1) |
| Boleum (1) | Hemicrambe (2) |
| Brassica (35) | Henophyton (1) |
| Cakile (7) | Hirschfeldia (2) |
| Carrichtera (1) | Kremeriella (1) |
| Ceratocnemum (1) | Moricandia (9) |
| Chalcanthus (2) | Morisia (1) |
| Coincya (6) | Muricaria (1) |
| Conringia (6) | Otocarpus (1) |
| Cordylocarpus (1) | Physorrhynchus (2) |
| Crambe (26) | Pseuderucaria (2) |
| Crambella (1) | Pseudofortuynia (1) |
| Didesmus (2) | Psychine (1) |
| Diplotaxis (27) | Quezeliantha (1) |
| Dolichorhynchus (1) | Raffenaldia (2) |
| Douepia (1) | Raphanus (2) |
| Enarthrocarpus (5) | Rapistrum (2) |
| Eremophyton (1) | Rytidocarpus (1) |
| Eruca (3) | Savignya (1) |
| Erucaria (9) | Schouwia (1) |
| Erucastrum (19) | Sinapidendron (5) |
| Euzomodendron (1) | Sinapis (5) |
| Fezia (1) | Succowia (1) |
| Foleyola (1) | Trachystoma (3) |
| Fortuynia (2) | Vella (5) |
| | Zilla (1) |

Within the tribe, Schulz (1919, 1923, 1936) also recognized, somewhat arbitarily on the basis of morphological characters, seven subtribes: Brassicinae, Cakilinae, Moricandiinae, Raphaninae, Savignyinae, Vellinae, and Zillinae. Gómez-Campo (1980) has since proposed a reduction to six subtribes with the inclusion of the Savignyinae in the Vellinae. The Brassicinae and Moricandiinae both include genera with elongated siliquose dehiscent fruit, while the other subtribes include those with reduced or "nucamentaceous" fruits.

Generic boundaries in the tribe are still somewhat arbitrarily drawn, and the establishment of clear-cut intergeneric relationships requires clarification. Unlike many of the small genera, the species are generally very distinct throughout the family, with fruit characters being the most reliably used structures for the proper identification of genera and species. Taxonomic debate in the tribe has centred most particularly upon the number of and relationships between the subtribes and genera (Hedge 1976, Al-Shehbaz 1985).

The genus *Brassica* is one of ten core genera in the subtribe Brassicinae, which also includes *Coincya*, *Diplotaxis*, *Eruca*, *Erucastrum*, *Hirschfeldia*, *Raphanus*, *Sinapidendron*, *Sinapis*, and *Trachystoma*. The Brassicinae is defined primarily on the basis of elongated (siliquose) dehiscent fruits, presence of median nectaries, and usually seeded beaks. Although morphologically quite distinct from subtribes Cakilinae, Vellinae, and Zillinae, its separation from the Raphaninae and Moricandiinae is less clear. Current generic circumscriptions within the subtribe Brassicinae have also been considered to be highly artificial by many taxonomists, with generic delimitation based primarily on only one or two morphological traits.

Systematists are continuing to re-evaluate relationships within the tribe Brassiceae by way of morphological, cytological, hybridization, isozyme and molecular analyses (studies reviewed in Warwick and Black 1991, 1993). Such research has confirmed many proposed species relationships, but has also indicated new relationships between genera and species. In particular, these studies have identified new potential sources of germplasm for *Brassica* crops, indicating that the range of germplasm important to the genus is much greater than previously recognized.

The following Guide to the wild germplasm of *Brassica* and allied crops (Tribe Brassiceae, family Cruciferae) will be divided into five parts as indicated below:

**I. Taxonomy and Genome Status** - [Complete list of genera and species in the tribe and their genomic status, containing cross references for commonly confused names];
by S.I. WARWICK

**II. Chromosome Numbers;**
by S.I. WARWICK & J.K. ANDERSON

**III. Interspecific and Intergeneric Hybridizations;**
by S.I. WARWICK & L.D. BLACK

**IV. Wild Species as Sources of Agronomic Traits** - [List of potentially useful agronomic traits and possible wild germplasm sources in the tribe];
by S.I. WARWICK

**V. Life History Data** [Summary of habitat and geographical distributions of all species indicated in part I.]
by S.I. WARWICK

The information provided in this guide is intended to be useful in providing direction for future genebank needs for these crops and for assisting biotechnologists and breeders wishing to utilize these genetic resources in their research programs.

## PART IV. WILD SPECIES IN THE TRIBE BRASSICEAE (Cruciferae) AS SOURCES OF AGRONOMIC TRAITS

The following publication is the fourth part of a guide to the wild germplasm of *Brassica* and allied crops (Tribe Brassiceae, family Cruciferae).

The potential of wild members of the tribe Brassiceae as sources of agronomic traits will be reviewed. In addition to traditional breeding methods, interspecific and intergeneric transfer of genes governing qualitative and quantitative characters from wild allies to cultivated forms will be facilitated with various in vitro methods, such as somatic cell genetics and recombinant DNA techniques (Sjödin 1992).

Examples of genetic variability in potential agronomic traits of germplasms of *Brassica* and related genera will be presented under the following sections:

1. **North American Germplasm**
   - A. North American Ethnobotany
   - B. Weed/Crop Genetic Exchange
   - C. Weed and Crop Species in Canada and U.S.A.
2. **Morphological Characters**
   - A. Hairs on cotyledons, juvenile leaves, fruits
   - B. Leaf thickness/waxiness
   - C. Petal colour
   - D. Resistance to pod shattering
   - E. Yellow Seed
   - F. Growth form
3. **Chemical Traits**
   - A. Fatty Acids
   - B. Glucosinolates (mustard oil glucosides)
   - C. Phenolic Choline Esters
4. **Photosynthesis**
5. **Cytoplasmic Male Sterility**
6. **Soil Adaptation:**
   - A. Saline
   - B. Calcareous
7. **Cold Tolerance**
8. **Drought Tolerance**
9. **Herbicide Resistance**
10. **Disease Resistance**
11. **Insect Resistance**
12. **Nematode Resistance**
13. **New Crops**

**1. North American Germplasm:**

The genus *Brassica* is considered a native of Eurasia and to have been introduced into the New World by European settlers around 400 years before present (B.P). Recent archaeological and ethnobotanical studies, reviewed in Jacobson et al. (1988), have provided evidence for a North American distribution of *Brassica*. *Brassica kaber* [=*Sinapis arvensis*] was found to have occurred in the northeastern United States as early as 8000 B.P. and was abundant and widespread by 2000 B.P.. These suggest the original existence of a semi-circumboreal distribution for *B. kaber* (and perhaps other *Brassica* spp.) which was maintained during the late-Quaternary with the range in North America changing during the glacial/interglacial cycles.

North American germplasm of the Tribe Brassiceae, whether naturalized introductions/crop escapes or native components, represents both a wild source of agronomic traits as well as agricultural weed problems.

Historically Native peoples of North America have used a number of "wild" *Brassica* spp. for both food and medicinal purposes:

**A. North American Ethnobotany: (Arnason et al. 1981, Jacobson et al. 1988)**

| | |
|---|---|
| *Brassica* spp. | - young shoots cooked as greens by Iroquois & Malecite Indian Tribes. |
| *Brassica nigra* (black mustard) | - seeds ground and used as snuff to cure head colds by the Meskwaki.<br>- leaves used to relieve toothaches and headaches by the Mohegans. |
| *Brassica hirta* (white mustard) | - used to treat tuberculosis by the Malecite and Micmac |
| *Brassica napus* (wild turnip) | - bark used to treat colds, cough, grippe and small pox by the Micmac<br>- used for chilbains by the Rappahannock |
| *Brassica oleracea* (wild cabbage) | - used for headaches by the Rappahannock |
| *Brassica rapa* | - was used as medicine by the Bois Fort Chippewa |

**B. Weed/Crop Genetic Exchange:**

Weed/crop interchange among members of the same cytodeme is possible and in studies on the origin of variation in wild *Raphanus sativus* in California Panetsos & Baker (1968) suggested that the introgression of wild radish, *R. raphanistrum*, characters appears to have been a major factor in converting the former crop, *R. sativus*, into a highly successful weed. Similar possibilities exist with crops grown in an area with dense populations of naturalized or escaped members of the same species or cytodeme.

Of more recent concern is the risk assessment of gene transfer between crops and weeds (intercytodeme exchange) [See PART III of the GUIDE].

These include:
-*Sinapis arvensis* with *Brassica nigra* and *B. juncea* (Bing et al. 1991);
-*Hirschfeldia incana* (= *Brassica adpressa*) with *Brassica napus* (Lefol et al. 1991);
-*Raphanus raphanistrum* and *Hirschfeldia incana* with *Brassica napus* (Kerlan et al. 1991).

**C. Weed and crop species in Canada & United States:**

| Weed and crop species [Common name] in Canada: | Distribution |
|---|---|
| -*Brassica juncea* (L.) Czern & Coss. [Indian mustard] | NT-M NF NS PE NB PQ ON MB SK AB BC |
| -*Brassica napus* L. [rape, canola] | NT-M LB NF PE NS NB PQ ON MB SK AB BC |
| -*Brassica nigra* (L.) Koch [black mustard] | NF SM NS PE NB PQ ON SK BC |
| -*Brassica oleracea* L. [cabbage] | NF PE PQ ON |
| -*Brassica rapa* L. [bird rape] (=*Brassica campestris* L.) | NT-M YT LB NF NS PE NB PQ ON MB SK AB BC |
| -*Cakile* spp.* [sea-rocket] | NF NS PE NB PQ ON BC |
| -*Conringia orientalis* (L.) Andrzejowski [hare's-ear mustard] | NF NS PE NB PQ ON MB SK AB BC |
| -*Diplotaxis erucoides* (L.) DC. | [rare] only Gaspé Pen, PQ |
| -*Diplotaxis muralis* (L.) DC. [sand-rocket] | NS PE NB PQ ON MB SK AB BC |
| -*Diplotaxis tenuifolia* (L.) DC. [wall-rocket] | NS NB PQ ON AB BC |
| -*Eruca vesicaria* (L.) Cav. ssp. *sativa* (Mill.) Thellung (=*E. sativa* Mill.) [garden-rocket] | [rare escape: PQ ON MB SK AB] |
| -*Erucastrum gallicum* (Willd.) O.E. Schulz [dog mustard] | NF NS PE NB PQ ON MB SK AB BC |
| -*Raphanus raphanistrum* L. [wild radish] | LB NF SM NS PE NB PQ ON (MB?) SK AB BC |
| -*Raphanus sativus* L. [radish] | NF NS PE NB PQ ON MB BC |
| -*Rapistrum perenne* (L.) All. | [rare] SK |
| -*Rapistrum rugosum* (L.) All. | [rare] PQ ON |
| -*Sinapis alba* L. [white mustard] (=*Brassica hirta* Moench) | YT NS PE NB PQ ON MB SK AB BC |
| -*Sinapis arvensis* L. [wild mustard] (=*Brassica kaber* (DC.) Wheeler) | NT-M YT LB NF SM NS PE NB PQ ON MB SK AB BC |

CODE: Distribution: Northwest Territories, District of Mackenzie, NT-M; Yukon Territory, YT; Labrador, LB; Newfoundland, NF; Saint Pierre and Miquelon, SM; Prince Edward Island, PE; Nova Scotia, NS; New Brunswick, NB; Quebec, PQ; Ontario, ON; Manitoba, MB; Saskatchewan, SK; Alberta, AB; British Columbia, BC.

[REFERENCES: Crompton et al. 1988, Scoggan 1979]

| Weed and crop species in United States: | Distribution |
|---|---|
| -*Brassica fruticulosa* Cyr. | CA |
| -*Brassica juncea* (L.) Czern & Coss. | Almost every state |
| -*Brassica napus* L. | AK CA CT IL IN IA KY ME MD MA NY OH TN VT VA WV |
| -*Brassica nigra* (L.) Koch | Almost every state |
| -*Brassica oleracea* L. | CA CT IL IA KY MA NY OH RI TX VT |
| -*Brassica rapa* L. (=*B. campestris* L.) | Almost every state |
| -*Brassica tournefortii* Gouan | AZ CA TX |
| -*Cakile spp.** | AK, Great Lakes, Atlantic and Pacific Coasts |
| -*Cakile maritima* Scop. | AL FL NJ |
| -*Coincya monensis* (L.) Greuter & Burdet | NC NY |
| -*Conringia orientalis* (L.) Andrzejowski | Almost every state |
| -*Crambe maritima* L. | OR |
| -*Diplotaxis muralis* (L.) DC. | AZ AR CA CT IL IN KS LA MA MI MN NE NJ NY NC OH OR PA SC SD TX UT WV |
| -*Diplotaxis tenuifolia* (L.) DC. | AZ CA CT DE IL IN KY MD MA MI NY OH OR PA TX VA |
| -*Eruca vesicaria* (L.) Cav. ssp. *sativa* (Mill.) Thellung (=*E. sativa* Mill.) | AZ CA CO CT IL IA KS MD MO MT NE NJ NM NY ND PA SD TX VT WA |
| -*Erucastrum gallicum* (Willd.) O.E. Schulz | CA FL ID IL IN KS KY LA ME MD MA MI MN MO MT NH NY ND PA SD TX VT WA WV WI WY |
| -*Hirschfeldia incana* (L.) Lagrèze-Fossat | CA NV |
| -*Raphanus raphanistrum* L. | Almost every state |
| -*Raphanus sativus* L. | Almost every state |
| -*Rapistrum rugosum* (L.) All. | CA LA MA NY PA TX |
| -*Sinapis alba* L. (=*Brassica hirta* Moench) | Almost every state |
| -*Sinapis arvensis* L. (=*Brassica kaber* L.) | Almost every state |

CODE: Distribution: Alabama, AL; Alaska, AK; Arizona, AZ; Arkansas, AR; California, CA; Colorado, CO; Connecticut, CT; Delaware, DE; Florida, FL; Georgia, GA; Idaho, ID; Illinois, IL; Indiana, IN; Iowa, IA; Kansas, KS; Kentucky, KY; Louisiana, LA; Maine, ME; Maryland, MD; Massachusetts, MA; Michigan, MI; Minnesota, MN; Mississippi, MS; Missouri, MO; Montana, MT; Nebraska, NB; Nevada, NV; New Hampshire, NH; New Jersey, NJ; New Mexico, NM; New York, NY; North Carolina, NC; North Dakota, ND; Ohio, OH; Oklahoma, OK; Oregon, OR; Pennsylvania, PA; Rhode Island, RI; South Carolina, SC; South Dakota, SD; Tennessee, TN; Texas, TX; Utah, UT; Vermont, VT; Virginia, VA; Washington, WA; West Virginia, WV; Wisconsin, WI; Wyoming, WY.

[REFERENCES: A summary from all available floras, Al-Shehbaz 1985, Lemke & Worthington 1991]

*NOTE: The genus *Cakile* [North American component includes *C. edentula* (Bigel.) Hook., *C. constricta* Rodman, *C. geniculata* (Robinson) Millspaugh, *C. lanceolata* (Willd.) O.E. Schulz] is generally considered the only member of the Brassiceae with indigeneous species in the New World.

2. **Morphological characters:**

**A. Hairiness (potential insect resistance):**

**Hairs on cotyledons** (Gómez-Campo & Tortosa 1974, Warwick pers. observ.):

-*Boleum asperum* (petiole & edge lamina)
-*Carrichtera annua* (petiole)
-*Ceratocnemum rapistroides* (petiole)
-*Crambe sventenii* (petiole, all over lamina)
-*Otocarpus virgatus* (petiole)
-*Psychine stylosa* (petiole & edge lamina)
-*Sinapis alba* (petiole and lamina)
-*Sinapis flexuosa* (petiole and lamina)
-*Vella anrhemerica* (petiole)
-*Vella pseudocytisus* (petiole and lamina)
-*Vella spinosa* (petiole)

**Hairs very dense on juvenile leaves:** (Gómez-Campo & Tortosa 1974)

-*Boleum asperum*
-*Brassica fruticulosa* ssp. *cossoniana*
-*Brassica incana* (wild C)
-*Brassica villosa* (wild C)
-*Coincya monensis*
-*Coincya rupestris*
-*Crambe arborea*
-*Crambe orientalis*
-*Crambe strigosa*
-*Euzomodendron bourgaeanum*
-*Hirschfeldia incana*
-*Sinapis alba*
-*Sinapis flexuosa*
-*Sinapis pubescens*
-*Vella pseudocytisus*
-*Vella spinosa*

**Hairs on fruit:** (Warwick pers. observ.)
-*Boleum asperum*
-*Carrichtera annua*
-*Ceratocnemum rapistroides*
-*Cordylocarpus muricatus*
-*Enarthrocarpus arcuatus*
-*Guiraoa arvensis*
-*Muricaria prostrata*
-*Otocarpus virgatum*
-*Psychine stylosa*
-*Rapistrum rugosum*
-*Sinapis alba*
-*Sinapis flexuosa*
-*Trachystoma aphanoneurum* (antrose hair)
-*Trachystoma ballii* (retrosed hair)
-*Trachystoma labasii* (antrose hair)
-*Vella mairei*
-*Vella pseudocytisus*

**B. Leaf thickness/waxiness: [drought & insect tolerance]:**

-*Brassica cretica*
-*Brassica oleracea* (Stoner 1990)
-*Diplotaxis harra*
-*Moricandia spp.*
-*Rytidocarpus*

**C. Petal colour (Yellow with the following exceptions):**

**White:**

-*Brassica "alboglabra"*
-*Brassica cretica* ssp. *cretica*
-*Brassica insularis*
-*Diplotaxis erucoides*
-*Erucastrum leucanthum*

**Purple/White:**

-subtribe Cakilinae (*Cakile*, *Didesmus*, *Erucaria*, *Reboudia*)

**Purple:**

-*Eruca setulosa*
-*Moricandia* spp. & *Rytidocarpus*
-subtribe Zillinae (*Foleyola*, *Fortuynia*, *Physorrhynchus*, *Schouwia*, *Zilla*)

**Apetalous flower:**

[NOTE: Problem with photosynthetic efficiency of rapeseed due to dense floral canopy which can reflect or absorb as much as 60% of the solar radiation (Rao et al. 1991).]

-*Conringia orientalis* [petals very small and occasionally absent] (Rich 1991)

**D. Resistance to pod shattering:**

| | |
|---|---|
| -*Brassica juncea* | (Prakash & Chopra 1988a) |
| -*Brassica macrocarpa** | (Mithen & Herron 1991) |
| -*Brassica hilarionis** | (Mithen & Herron 1991) |
| -*Brassica tournefortii* | (Salisbury 1989) |
| -*Conringia orientalis* | (Salisbury 1989) |
| -*Enarthrocarpus* spp. | (Warwick pers. observ.) |
| -*Hirschfeldia incana* | (Salisbury 1989) |
| -*Raphanus* spp. | (Agnihotri et al. 1991) |

*: partial resistance

**E. Yellow seed:** (Sobrino-Vesperinas et al. 1991):

-*Brassica carinata*
-*Brassica juncea*
-*Brassica rapa*
-*Sinapis alba*

**F. Growth form:**

Annual, winter annuals, biennials, perennials, woody shrubs

Sub-trees:
Canary Island *Crambe* spp. (eg. *C. arborea* & *C. strigosa*)

Burial of fruit underground (geogarpy):
-*Morisia monanthos*
-*Raffenaldia primuloides*

**3. Chemical Traits:**

**A. Fatty Acids:** (Reviewed by Kumar & Tsunoda (1980) for tribe):

There is variation in both the amount of oil and fatty acid composition.

Additional surveys of wild species:
Vioque et al. (1990) - 4 wild *Brassica* spp.
Yaniv et al. (1991) - 11 wild taxa in tribe

High erucic acid (22:1) (>45-50%):

| | |
|---|---|
| -*Brassica cretica* | (Yaniv et al. 1991) |
| -*Crambe abyssinica* and *C. hispanica* | (Yaniv et al. 1991) |
| -*Eruca vesicaria* (includes *E. sativa*) | (Yaniv et al. 1991) |
| -*Sinapis alba* | (Persson 1986, Yaniv et al. 1991) |

**B. Glucosinolates: (Mustard oil glucosides)**

Characteristic odours and flavours of crucifers are due to the glucosinolate hydrolysis products. These have long been of toxicological interest (Daxenbichler et al. 1991), as certain glucosinolates and their degradation products have shown adverse effects on animals. More recently there is an interest in their pharmacological role in the prevention of disease and in their use as insect attractants/repellants, etc.. Greater than 60 glucosinolates are present in the Cruciferae, and many of these are unique to certain species and genera.

**Surveys of glucosinolates in wild members of the tribe:**

| | |
|---|---|
| Al-Shehbaz & Al-Shammary (1987) | - 13 species [total of 51 cruciferous species] |
| Daxenbichler et al. (1991) | - 64 species [total of 259 cruciferous species] |
| El-Menshawi et al. (1980) | - 3 species of *Zilla* |
| Horn & Vaughan (1983) | - 14 species of *Brassica* |
| Mithen et al. (1987a) | - 9 species of the wild *Brassica oleracea* complex |
| Rodman (1974, 1976) | - 13 species of *Cakile* |

**C. Aromatic Phenolic Choline Esters** (such as sinapine):

Bouchereau et al. (1991) surveyed 23 taxa in Tribe and found both specific and generic differences.

**4. Photosynthesis (All $C_3$ plants with following exception):**

$C_3$-$C_4$ Intermediate:

-*Moricandia* spp. [*M. arvensis*, *M. nitens*, *M. sinaica*, *M. spinosa*, and *M. suffruticosa*]
(Bauwe 1983, Hylton et al. 1988)

**5. Cytoplasmic male sterility:**

| | |
|---|---|
| -*Brassica oxyrrhina* | (Prakash & Chopra 1988b) |
| -*Brassica tournefortii* | (Pradhan et al. 1991)) |
| -*Diplotaxis harra* | (Klimaszewska & Keller 1988) |
| -*Diplotaxis muralis* | (Hinata & Konno 1979) |
| -*Hirschfeldia incana* | (Horovitz & Galil 1972) |
| -*Raphanus sativus* | (Ogura 1968) |

**6. Soil adaptation:**

**A. Tolerance to saline soils:**

(succulent annuals of coastal strand habitats)
-*Cakile maritima** [North American component includes *C. edentula*]
-*Crambe maritima*
-*Raphanus raphanistrum* ssp. *martimus* [=*Raphanus maritimus*]

NOTE: Unique ecological specialization for these three groups is unknown elsewhere in the Cruciferae (Al-Shehbaz 1985).
*NOTE: Habitat for all members of genus *Cakile* with exception of *C. arabica*

**B. Tolerance to calcareous (limestone) soils:**

-*Euzomodendron bourgaeanum*
-*Moricandia moricandiodes*

**7. Cold tolerance:**

Mountainous habitats (elevations > 2000-2500 m or above snow line)
-*Brassica nivalis* (Mt. Olympus, Greece)
-*Brassica jordanoffii* (Mt Pirin Planina, s.w. Bulgaria)
-*Coincya richeri* (S.W. Alps in France & Italy- occurs above snowline 1750-2500m (Leadlay & Heywood 1990)

-*Erucastrum abyssinicum* & *E. pachypodum*, Ethiopian Highlands (> 3000m) (Al-Shehbaz 1985)

**8. Drought tolerance (desert endemics):**

**A. Annuals:**

| | |
|---|---|
| -*Brassica juncea* | (Downey & Röbbelen 1989) |
| -*Brassica tournefortii* | (Salisbury 1989) |
| -*Carrichtera annua* | (Boaz et al. 1990) |
| -*Diplotaxis acris* & *D. harra* | (Boaz et al. 1990) |
| -*Enarthrocarpus strangulatus* | (Boaz et al. 1990) |
| -*Eruca sativa* | (Sun et al. 1991) |
| -*Erucaria boveana* | (Boaz et al. 1990) |
| -*Erucaria microcarpa* & *E. uncata* | (Boaz et al. 1990) |
| -*Moricandia* spp. | (McVetty et al. 1989) |
| -*Pseuderucaria clavata* | (Boaz et al. 1990) |
| -*Savignya parviflora* | (Boaz et al. 1990) |
| -*Schouwia purpurea* | (Boaz et al. 1990) |
| -*Sinapis alba* | (Downey & Röbbelen 1989) |

**B. Desert shrubs:**
-subtribe Zillinae
(*Foleyola, Fortuynia, Physorrhynchus, Zilla*)

**9. Herbicide resistance:**

**A. Atrazine resistance:**
-*Brassica rapa* (Quebec) (Warwick 1991, Warwick & Black 1993b)
-*Sinapis arvensis* (Ontario) (Warwick 1991)

**B. Phenoxy resistance:**
-*Sinapis arvensis* (Manitoba) (Morrison, pers. comm.)

**10. Disease resistance:**

**A. *Albugo candida* -- White rust**

Resistance to A. *candida* races/isolates has been found at both the *Brassica* species and cultivar levels.

-*Brassica napus*: Canadian cultivars highly resistant to western Canadian isolates (Liu & Rimmer 1991)
-*Brassica carinata*: resistance common, *B. rapa*, *B. juncea*, *B. nigra*: resistance more limited in latter three (Liu & Rimmer 1991, Gulati et al. 1991, Kolte et al. 1991)
-*Raphanus sativus* (Williams & Pound 1963, Kolte et al. 1991)

**B. *Alternaria brassicae* -- Blackspot/ Alternaria blight**

-*Brassica spinescens* (Agnihotri et al. 1991)
-*Eruca sativa*: highly resistant to a Canadian isolate (Conn & Tewari 1986, Tewari 1991)
-*Sinapis alba* (Kolte 1985, Brun et al. 1987, Sharma & Singh 1992)

[NOTE: Highest resistance in crucifers found in *Camelina sativa* (False flax) and *Capsella bursa-pastoris* (Shepherd's purse) (Conn et al. 1988, reviewed in Tewari 1991)]

**C. *Leptosphaeria maculans* [=*Phoma lingam*] -- Blackleg**

-*Brassica carinata*, *B. juncea*, *B. nigra* (Rimmer & van den Berg 1992)
-*Brassica insularis*, *B. atlantica*, *B. macrocarpa*: Members of wild *B. oleracea* complex]
(Mithen et al. 1987b, Mithen & Herron 1991, Mithen & Magrath 1992)
-Weedy species of *Carrichtera*, *Diplotaxis*, *Hirschfeldia*, *Raphanus*, *Rapistrum* and *Sinapis* (Salisbury 1987)

**D. *Peronospora parsitica* -- Downy mildew**

-wild *Brassica oleracea* (Greenhalgh & Mitchell 1976)

**E. *Plasmodiophora brassicae* -- Clubroot**

-*Raphanus spp.* (Crute et al. 1980, Long et al . 1992)

**F. Virus Resistance(Immunity):**

Turnip mosaic virus (common strain TuMV-S1)

-*Raphanus raphanistrum* (Stobbs & Stirling 1990; surveyed 6 weedy species in the tribe]

**G. *Sclerotinia sclerotiorum* -- Sclerotinia stem rot**

[NOTE: occurs worldwide, infects at least 225 genera of host plants, including weeds (Purdy 1979) can cause serious losses in yield of canola due to lodging and premature shattering of seedpods]
-no known source of resistance

**11. Insect resistance:**

**A. Flea beetle [*Phyllotreta cruciferae* and *P. striolata*]**

Flea beetles are the most important insect pests of oilseed crucifer crops in the Prairies (Canada) and Northern Great Plains (USA). Oilseed rape is most vulnerable in the spring when adult flea beetles attack newly emerged seedlings producing pits on leaves and cotyledons, that when severe can cause seedling mortality.

-*Brassica incana* (Bodnaryk in prep.)
-*Brassica villosa* (Bodnaryk in prep.)
-*Crambe abyssinica* (Anderson et al. 1992)
-*Sinapis alba* (Bodnaryk & Lamb 1991, Lamb 1980)

**B. Lepidopterous pests --**

-*Brassica oleracea* - Glossiness (Stoner 1990)

**C. Cabbage aphid [*Brevicoryne brassicae*]**

-*Sinapis alba* (Thompson 1963)

**12. Nematode resistance:**

Beet cyst nematode (*Heterodera schachtii*)

-*Raphanus sativus* into *Brassica napus*
(Thierfelder et al. 1991, Lelivelt & Krens 1992)

-*Sinapis alba* into *Brassica napus* (Lelivelt et al. 1993)
-*Sinapis alba* (Thierfelder et al . 1991)

**13. New crops:**

Source for vegetables, fodder, condiments and oil

-"Brassicoraphanus": (raparadish) (Lange et al. 1989)

-*Crambe abyssinica*: (Erickson & Bassin 1990)
Insect tolerant & high levels of erucic acid (industrial oil)

-*Eruca sativa*: (Sun et al. 1991)
Drought tolerant & high levels of erucic acid (industrial oil)

-*Sinapis alba*: (Downey & Röbblen 1989)
Condiment mustard - c. 57,000 ha grown annually in Canada
Drought tolerance and tolerance to high temperatures, insect tolerance

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