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The Biology of *Brassica rapa* L.

A companion document to the *Assessment Criteria for Determining Environmental Safety of Plants with Novel Traits*.

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Part A General Information

A1.0 Background

The Canadian Food Inspection Agency (CFIA) is responsible for regulating the field testing in Canada of agricultural and horticultural crop plants with novel traits (PNTs). PNTs are defined as a plant variety/genotype possessing characteristics that demonstrate neither familiarity nor substantial equivalence to those present in a distinct, stable population of a cultivated species in Canada and that have been intentionally selected, created or introduced into a population of that species through a specific genetic change. Familiarity is defined as the knowledge of the characteristics of a plant species and experience with the use of that plant species in Canada. Substantial equivalence is defined as the equivalence of a novel trait within a particular plant species, in terms of its specific use and safety to the environment and human health, to those in that same species, that are in use and generally considered as safe in Canada, based on valid scientific rationale. Environmental safety assessment criteria include:

- potential of the PNT to become a weed of agriculture or be invasive of natural habitats
- potential impact of the PNT or its gene products on non-target species, including humans
- potential for gene-flow to wild relatives whose hybrid offspring may become more weedy or more invasive
- potential for the PNT to become a plant pest
- potential impact on biodiversity

The PNTs may be developed using traditional plant breeding techniques or other methodologies such as recombinant DNA technologies. Regulated field testing is necessary when PNTs are: (1) considered unfamiliar when compared with products already in the market; (2) not considered substantially equivalent to similar, familiar plant types already in use, and regarded as safe.

Before PNTs may be authorized for unconfined release, they must be assessed for environmental safety. Regulatory Directive Dir94-08: *Assessment Criteria for Determining Environmental Safety of Plants with Novel Traits* describes the criteria and information requirements that must be considered in the environmental assessment of PNTs to ensure environmental safety in the absence of confined conditions.

A2.0 Scope

The present document represents a companion document to Dir94-08: *Assessment Criteria for Determining Environmental Safety of Plants with Novel Traits*. It is intended to provide background information on the biology of *Brassica rapa* L., its centres of origin and related species. Emphasis has been placed on detailing potential hybridization events between *B. rapa* and its close relatives. Discussion is limited to hybridization events that can occur in nature and result in fertile offspring.

Such species-specific information will serve as a guide for addressing some of the requirements of Part D of Dir94-08. Specifically, it will be used to determine if there are significantly different/altered interactions with other life forms resulting from the PNTs novel gene products which could potentially cause the PNT to become a weed of agriculture, become invasive of natural habitats, or be otherwise harmful to the environment.

The conclusions drawn in this document about the biology of *B. rapa* relate only to plants of this species with no novel traits.

Part B The Biology of *Brassica rapa*

Brassica rapa and *B. campestris* were first described as two species by Linnaeus, with *B. rapa* being the turnip form and *B. campestris* the wild weedy form. Metzger in 1833 concluded that these were the same species and combined the taxa under the name *B. rapa* (Toxeopus *et al.*, 1984).

B1.0 General Description and Use as a Crop

Brassica rapa L. belongs to the Cruciferae (Brassicaceae) family, also known as the mustard family. The name crucifer comes from the shape of flowers, with four diagonally opposite petals in the form of a cross.

Brassica rapa has green foliage, leaves glabrous or slightly hispid when young, and the upper leaves partially clasping the stem. The stems are well branched, although the degree of branching depends on biotype / variety and environmental conditions. Branches originate in the axils of the highest leaves on the stem, and each terminates in an inflorescence. Lower leaves are sparingly toothed or pinnatifid and petioled, while upper leaves are sessile, subentire, oblong lanceolate and often constricted above the base. The inflorescence is an elongated raceme, the flowers are pale yellow, densely clustered at the top with open flowers borne at or above the level of terminal buds, and open upwards from the base of the raceme (Downey *et al.*, 1980).

There are three well defined groups of *B. rapa* (A genome, n=10), based on their morphological characteristics: (1) the oleiferous or oil-type rape, often referred to in Canada as Polish rape or summer turnip rape, of which canola is a specific form having low erucic acid in its oil and low glucosinolate content in its meal protein; (2) the leafy-type *B. rapa*, including the chinensis group (pak-choi, celery mustard), the pekinensis group (chinese cabbage), and the perviridis group (tendergreen); and (3) the rapiferous-type *B. rapa*, comprising the rapifera group (turnip, rapini), and the ruvo group (turnip broccoli, Italian turnip) (Hortus Third, 1976; Prakash and Hinata, 1980). The turnip and vegetable types are important as vegetable sources in many parts of the world and are used as forages for sheep and cattle. This document is written for the oleiferous rape.

B. rapa can be subdivided into: (1) Indian forms; subspecies *trilocularis* (Roxb.) Hanelt. known as yellow sarson and subsp. *dichotoma* (Roxb.) Hanelt. known as both toria and brown sarson, and; (2) western European and north American form; *B. rapa* subsp. *oleifera* (DC.) Metzg. (Kimber and McGregor, 1995).

The exact time and place of domestication are unknown, but Indian Sanskrit writings of 2000 to 1500 BC refer directly to oilseed rape and mustard, as do Greek, Roman and Chinese writings of 500 to 200 BC (Downey and Röbbelen, 1989). In Europe, domestication is believed to have occurred in the early middle ages and commercial plantings of rapeseed were recorded in the Netherlands as early as the 16th century. At that time rapeseed oil was used primarily as an oil for lamps. Later it became used as a lubricant for steam engines. Although used widely as an edible oil in Asia, only through breeding for improved oil quality, and through the development of improved processing techniques, has rapeseed oil become important in western nations. Since the Second World War, as a result of improved oil and meal quality, rapeseed production in Europe and Canada has increased dramatically. China, India, Europe and Canada are now the top producers, although there is potential for the crop to be successfully grown in the United States, South America and Australia where annual production increased sharply over the last few years.

Today “double low” commercial varieties of both *B. napus* and *B. rapa* dominate the oilseed Brassica production area in developed countries. These "double low" varieties are characterized as having a very low (<1%) content of erucic acid in the fatty acid profile of the seed storage lipid and a very low content of glucosinolates (<18 µmoles per gram seed at 8.5% moisture) in their seed and meal. The term “canola quality” is normally applied to seed, oil and meal from such varieties.

B. rapa was the dominant species in western Canada in the early 1970's (Downey *et al.*, 1974). Similar acreages of *B. napus* and *B. rapa* were grown on the prairie provinces in the late 1980's but in the 1990's the proportion of the production area sown to *B. rapa* diminished to about 15 to 20%. The main *B. rapa* production regions in Canada are the province of Alberta, the Peace River region of British Columbia and northern Saskatchewan. The Manitoba acreage is primarily *B. napus*. *B. rapa* withstands spring frosts better than *B. napus* and generally requires fewer frost-free days to complete its life cycle. *B. rapa* varieties therefore tend to be grown north of the areas in which *B. napus* is grown. Both spring and winter annual forms occur but only spring forms are grown. The winter forms are more productive than the spring forms but are not sufficiently winter hardy to be grown in Western Canada (Downey and Röbbelen, 1989).

B2.0 The Centres of Origin of the Species

Wild *B. rapa* subsp. *oleifera* [includes *var. sylvestris*] is regarded as the species from which *var. rapa* L. (cultivated turnip) and *var. silvestris* (Lam.) Briggs (turnip-rape) originated. It is native throughout Europe, Russia, Central Asia and the Near East (Prakash and Hinata, 1980), with Europe proposed as one centre of origin. The Asian and Near Eastern type may have originated from an independent centre of origin in

Afghanistan which then moved eastward as it became domesticated. Prakash and Hinata (1980) suggest that oleiferous *B. rapa* developed in two places giving rise to two different races, one European and the other Asian. Recent evidence (Song and Osborn, 1992) through analyses of chloroplast and mitochondrial DNA suggests that *B. montana* (n = 9) might be closely related to the prototype that gave rise to both cytoplasms of *B. rapa* and *B. oleracea*.

Typically, the range of *B. rapa* extends to coastal lowlands, plateaus, hills, and montane areas up to 2300 m (Warwick & Francis, 1994). In Europe, the winter form has become a common yellow crucifer of roadsides, waste and cultivated ground, docks, cities and towns, arable fields and riverbanks. In the British Isles, for instance, it has escaped from cultivation and is naturalised wherever oil-seed rape is grown. It is a relatively recent introduction into Canada and the United States, and is described as an occasional weed, escape or volunteer in cultivated fields (Munz, 1968; Muenscher, 1980). In Canada, it is found in disturbed habitats, typically in crops, fields, gardens, roadsides and waste places (Warwick and Francis, 1994).

B3.0 The Reproductive Biology of *B. rapa*

B. rapa, with the exception of the Indian yellow sarson form, is an obligate outcrosser due to the presence of self-incompatible genes. As a result, little or no seed is set when *B. rapa* is self-pollinated. *B. rapa* pollen is sticky but lighter than that of *B. napus* (K. Falk and K. Downey, personal communications). As with *B. napus*, relatively high pollen levels can result from synchronously blooming *B. rapa* fields and the concentration of pollen, as indicated by outcrossing studies, decreases rapidly with increasing distance from the source of pollen (Stringam and Downey, 1978; Raney and Falk, 1998). Under field conditions, *B. rapa* pollen is transferred from plant to plant primarily through physical contact between neighbouring plants. It can be also transferred over longer distance by wind and insects. To minimize contamination of *B. rapa* foundation seed plots, a distance of 400 metres is required from other contaminating source of *B. rapa* pollen (CSGA, 1994).

Pollinating insects, in particular honey bees (*Apis mellifera*) and bumble bees (*Bombus* sp.), are believed to play a major role in the transfer of pollen over long distances. The dynamics of bee mediated pollen movement depend on the quantity of pollen available (size and density of donor population), the relative size, location and direction of the receiving populations from the pollen source, as well as on the environmental conditions and insect activity (Levin and Kerster, 1969; Ellstrand *et al.*, 1989; Klinger *et al.*, 1992; Stringam and Downey, 1978; Raney and Falk, 1998). Generally, the weather conditions at flowering time will influence pollination, for example a reduction in bee activity on cold or windy days.

B4.0 Brief Outlook of Agronomic Practices for the Oleiferous *B. rapa* (based on Thomas, 1994)

The spring-type oleiferous *B. rapa* is a cool-season crop. It is widely adapted, and performs well in a range of soil conditions, provided that moisture and fertility levels are adequate. Air and soil temperatures influence canola plant growth and productivity. The optimum temperature for maximal growth and development is just over 20 °C, and it is best grown between 12 °C and well below 30 °C. After emergence, seedlings prefer relatively cool temperatures up to flowering; high temperatures at flowering will hasten the plant's development, reducing the time from flowering to maturity.

B. rapa is commonly swathed at physiological maturity when 30- 50% of the seed on the plant have begun to turn from green to brown or yellow. The seed is combined at full maturity when nearly all the seeds have turned colour. The use of desiccants results in rapid and more uniform maturity thus allowing the crop to be straight combined. Furthermore, *B. rapa* is more resistant to shattering compared to *B. napus* making *B. rapa* easier to straight combine.

Agronomic practices of *B. rapa* are influenced by the increased awareness of soil conservation issues. Minimal or no till *B. rapa* production are recommended, where most of the crop residue and stubble are left on the soil surface to trap snow, reduce snow melt run-off, stop wind and water erosion of the soil, and increase soil water storage. Reduced tillage techniques, however, are only effective when they are combined with a good systematic weed control program.

Weeds can be one of the most limiting parameters in rapeseed production. The closely related cruciferous weeds, e.g. wild mustard (*Sinapis arvensis*), stinkweed (*Thlaspi arvense*), shepherd's purse (*Capsella bursa-pastoris*), ball mustard (*Neslia paniculata*), flixweed (*Descurainia sophia*), wormseed mustard (*Erysimum cheiranthoides*), hare's-ear mustard (*Conringia orientalis*), common peppergrass (*Lepidium densifolium*), etc. are often problematic. Spring-type oilseed rape does not compete well with weeds in the early growth stages, because it is slow growing and slow to cover the ground. Weeds must be controlled early to avoid yield loss due to competition. Although the crop can be attacked by a number of insect pests, insect control must be carefully designed to reduce unnecessary and costly pesticide applications, opportunities for resistance buildup in insects, and damage to honeybees and native pollinating insects. Diseases can be severe in large production areas, and are greatly influenced by cultivation practices and environmental factors. To control disease, growers are advised to implement disease management programs (please refer to Table 2 for examples of *B. rapa* pests and diseases).

Generally, Brassicas should not be grown on the same field more often than once every four years, to prevent the buildup of diseases, insects, and weeds. Chemical residues from herbicides and volunteer growth from previous crops including rapeseed crops grown for different oil types are also important factors to consider when selecting sites.

Breeding of *B. rapa* is commonly done using simple recurrent selection procedures to prevent inbreeding depression. *Brassica rapa* shows considerable heterosis for yield, with up to 40% yield increases and there is consequently a strong interest in developing hybrid or synthetic cultivars (Falk *et al.*, 1998). Synthetic cultivars are the result of random matings between selected parental lines, which give rise to both hybrids and progeny (sibs) from matings within the same parental lines (Buzza, 1995; Falk *et al.*, 1998). The first *B. rapa* synthetics were registered in Canada in May 1994 under variety names CASH, Hysyn 100 (Falk and Stoenescu, 1996a), Hysyn 110 (Falk and Stoenescu, 1996b) and Maverick (CFIA, 1999).

B5.0 Cultivated *B. rapa* as a Volunteer Weed

As with all crops cultivated and harvested on a field scale, some seeds may escape harvest and remain in the soil until the following season when they germinate either before or following seeding of the succeeding crop. In some instances the volunteers may give considerable competition to the seeded crop and cause deterioration of quality of the crop harvest. In such instances, chemical and/or mechanical control is essential.

The problem of volunteer plants in succeeding crops is common to most field crop species. Much depends on the management practices used in the production of the crop, i.e. whether the plants have dispersed seed at the time of harvest, the setting of the harvesting equipment, and speed of the harvesting operation which will determine whether more or less seed is lost by the harvester. Brassica crops produce large numbers of small sized seed, which without proper management practices can result in severe volunteer problems in succeeding crops. Similar problems may be encountered with cultivated *B. juncea* and *B. napus* varieties. Shattered seeds of *B. rapa* can be induced to become dormant, especially if buried in the soil, although a suitable soil treatment after the harvest can considerably reduce the volunteer problem.

B6.0 Summary of *B. rapa* Ecology

B. rapa is a plant of disturbed habitats. In unmanaged ecosystems this species may be considered a primary colonizer, i.e. a plant species that is the first to take advantage of disturbed land where they would compete against plants of similar types for space. Unless the habitats are disturbed on a regular basis, such as on cliff edges, river edges and the edges of pathways made by animals, populations of these types of plants will become displaced by intermediaries and finally by plants that will form climax ecologies such as perennial grasses on prairies, and tree species and perennial shrubs in forests.

There is potential for *B. rapa* to become naturalized in disturbed habitats, such as roadsides, industrial sites, waste places, and crop lands. Evidence for this can be found in the plant records of *B. rapa* from countries where *B. rapa* has been introduced as a crop plant. The ability of *B. rapa* to compete for space with other primary colonizers will affect whether it becomes naturalized in a particular area. This will also be dependent on the suitability of the climate, soil conditions, etc. of that area.

In crop production systems, poor management practices and insufficient resistance to pod shattering may cause a large reduction in the numbers of seed of *B. rapa* harvested. This may, especially at high crop densities, cause volunteer weed problems in succeeding crops and also contamination of such crops with respect to their seed quality, especially if they are present at high density.

B. rapa is not listed as a noxious weed in the Weed Seed Order (1986). Weeds of Canada (Frankton and Mulligan, 1993) reports that *B. rapa* is distributed widely across all provinces in Canada. Field research shows that *B. rapa* occurs largely as a volunteer weed in cultivated land in the Western provinces (Thomas and Frick, 1998; Thomas *et al.*, 1998). Reports of *B. rapa* as a weed are more frequent in Québec and in the eastern provinces of Canada. In the corn fields of eastern Canada where continuous use of the herbicide Atrazine was employed, selection pressure resulted in the identification of *B. rapa* plants tolerant to the triazine family of herbicides (Maltais and Bouchard, 1978). Additionally, bird rape, a wild *B. rapa* biotype, is a minor weed in limited grain field acreages in Ontario (Alex and Switzer, 1976).

Part C The Close Relatives of *Brassica rapa*

C1.0 Inter-Species/Genus Hybridization

In considering the potential environmental impact following the unconfined release of genetically modified *B. rapa*, it is important to have an understanding of the potential for development of hybrids through interspecific and intergeneric crosses between the crop and its related species. The development of such hybrids could result in the introgression of the novel traits into these related species and result in:

- the related species becoming more weedy in agriculture lands or invasive of natural ecosystems
- altered environmental interactions potentially causing harm to the environment or to human health and safety.

For a trait to become incorporated into a species genome, it is first necessary for hybrid intermediaries to be produced, and secondly that recurrent backcrossing of plants of that species to hybrid intermediaries occur, and for the resulting progeny to be viable and capable of reproducing.

While interspecific and intergeneric crosses have been made between *B. rapa* and its relatives, many have necessitated intervention in the forms of ovary culture, embryo rescue and protoplast fusion. Reported in the literature and cited below in Table 1 are interspecific and intergeneric hybrids that were obtained by sexual matings between *B. rapa* and related species that are present in Canada (Warwick and Black, 1993; Prakash and Hinata, 1980).

Table 1: Interspecific and Intergeneric Hybrids obtained sexually between *Brassica rapa* and those related species that are present in Canada (Note: F1 = F1 hybrids produced; F2 = self-pollinated progeny produced from F1 hybrids; BCP = backcross progeny)

| Cross | Outcome | Reference |
|--|--------------------|--|
| <i>B. napus</i> x <i>B. rapa</i> | F1, F2, BCP | Morinaga, 1929; U, 1935; Bing <i>et al.</i> , 1991 Jørgensen & Andersen, 1994; Mikkelsen <i>et al.</i> , 1996 |
| <i>B. rapa</i> x <i>B. napus</i> | F1, F2, BCP | Morinaga, 1929; U, 1935; Bing <i>et al.</i> , 1991; Falk, 1991; Jørgensen & Andersen, 1994; Mikkelsen <i>et al.</i> , 1996 |
| <i>B. rapa</i> x <i>B. nigra</i> | F1 | Mizushima, 1950; Prakash, 1973; Hinata <i>et al.</i> , 1974; Mattsson, 1988; Bing <i>et al.</i> , 1996 |
| <i>B. nigra</i> x <i>B. rapa</i> | F1 | Hinata <i>et al.</i> , 1974 |
| <i>B. rapa</i> x <i>B. oleracea</i> | F1 | Wojciechowski, 1985; Mattsson, 1988 |
| <i>B. oleracea</i> x <i>B. rapa</i> | F1 | Ellerström, 1978; Wojciechowski, 1985 |
| <i>B. rapa</i> x <i>B. carinata</i> | F1 | Takeda, 1975; Falk, 1991 |
| <i>B. carinata</i> x <i>B. rapa</i> | F1 | Mizushima, 1950 |
| <i>B. juncea</i> x <i>B. rapa</i> | F1, BCP | Sinskaia, 1927; Olsson, 1960; Katiyar and Chamola, 1995 |
| <i>B. rapa</i> x <i>Raphanus sativus</i> | F1, F2 | Ellerström, 1978; Dolstra, 1982 |
| <i>R. sativus</i> x <i>B. rapa</i> | F1 | Ellerström, 1978 |
| <i>B. rapa</i> x <i>S. arvensis</i> | F1 | Mizushima, 1950 |
| <i>Diplotaxis eruroides</i> x <i>B. rapa</i> | F1 | Hinata <i>et al.</i> , 1974; Vyas <i>et al.</i> , 1995 |
| <i>D. muralis</i> x <i>B. rapa</i> | F1 | Salisbury, 1989; Lefol <i>et al.</i> , 1997 |
| <i>D. tenuifolia</i> x <i>B. rapa</i> | F1 | Salisbury, 1989 |
| <i>B. rapa</i> x <i>Erucastrum gallicum</i> | F1 | Lefol <i>et al.</i> , 1997) |

Some hybrids, such as the *B. rapa* x *B. napus*, *B. napus* x *B. rapa* and *B. rapa* x *B. nigra* hybridizations, resulted from field outcrossing studies reported by Bing *et al.* (1991, 1996). Others were achieved through hand pollination, usually through emasculation of the female plant followed by transfer of pollen from the male plant using a paint brush.

Interspecific crosses may result in progeny that exhibit partial fertility/sterility. This may be influenced by the chromosome number of the cultivated species and relatives. Many hybrids fail to occur due to a lack of development of the endosperm (tissue resulting from the fertilization of the two polar nuclei of the embryo sac by a male reproductive nucleus).

Although there are many exceptions, a 2:1 ratio, or higher, of maternal and paternal chromosomes improves the chance for a successful cross (Nishiyama and Inomata, 1966). For example, the pollination of a tetraploid female parent by a diploid male usually produces seed while the reciprocal cross is less productive or produces no seed. Also of interest is the finding that partially fertile plants produced by the interspecific cross, *B. napus* x *B. rapa*, are able to set seed upon selfing.

Flowering periods of *B. rapa* and other species, such as *B. napus*, *B. nigra*, are critical for hybridization events to occur. Flowering periods, which are largely environmentally influenced, must overlap at least partially. To evaluate hybridization potential, it is important to know the flowering chronology of both the cultivated plant and related species, physical distance between species with potential to hybridize; occurrence of vectors for pollination, and in the case of pollination by insects, the frequency of the potential pollination, activity and behaviour.

For a trait to become incorporated into a species genome, recurrent backcrossing of plants of that species by hybrid intermediaries, and survival and fertility of the resulting offspring, is necessary.

C2.0 Potential for Introgression from cultivated *B. rapa* into Relatives

The hybridization events listed in Table 1 are intended to assist the assessment of the potential for introgression of novel traits introduced from cultivated *B. rapa* into wild relatives. Several factors should be considered when evaluating the potential of gene flow from one species to another, including: cross compatibility of the species involved; direction of the cross; viability of the seed developed from the interspecific or intergeneric cross; and fertility of the hybrid. The probability of gene transfer across the Brassicas is quite high due to the cross-compatibility of the members of the triangle of U.

The first step in this assessment is to determine which, if any, of the potential mates of *B. rapa* are recorded as present in the geographic region where the cultivation is proposed. Should there be potential wild relative mates present, the frequency of hybridization events and the potential for environmental impact should introgression occur would then be considered.

Wild populations of *B. rapa* (bird rape) exist in agricultural sites and gene flow from *B. rapa* crop plants to these individuals is likely to occur.

Bing *et al.* (1991) suggested that of the crosses they attempted, there was potential for hybrids between *B. napus*, *B. juncea* and *B. rapa* to produce viable seed that could survive to the next generations. These three species are widely grown as crops for the production of both canola and mustard.

Sinapis arvensis is perhaps the worst of the weedy Brassica relatives, especially in the major canola growing areas of Manitoba, Saskatchewan and Alberta. Its presence was recorded as high as 45% in surveyed canola fields in Manitoba (Thomas *et al.*, 1998).

Hybrid combinations successfully created using *B. rapa* as a female parent may be relevant to gene flow considerations as they could act as genetic bridges to other related *Brassica* species. Of concern would be the role of *B. juncea* as a genetic bridge to either *B. nigra* or *S. arvensis*, as *B. juncea* can hybridize with both of these species (Bing *et al.*, 1991).

C3.0 Occurrence of *B. rapa* and Related Species in Canada

Of the above listed crosses, *B. carinata* is not reported as present in Canada (Warwick, 1993; Warwick *et al.*, 1999), although it may provide a future source of genes responsible for large yellow seeds, disease and pod shattering-resistance for canola breeding. There are only old records of *Diplotaxis eruroides* reported in the Gaspé peninsula of Québec. *Brassica oleracea*, apart from the wild types in their original habitats in Europe, is rarely found outside of cultivation.

Of the other species:

- The wild form of *B. rapa* (bird rape) is recorded in the Northwest Territories, District of Mackenzie (NT-M), Yukon Territory (YT), Labrador (LB), Newfoundland (NF), Nova Scotia (NS), Prince Edward Island (PE), New Brunswick (NB), Québec (PQ), Ontario (ON), Manitoba (MB), Saskatchewan (SK), Alberta (AB) and British Columbia (BC). *Weeds of Canada* (Frankton and Mulligan, 1993) suggests it is sometimes abundant and that in some parts of Eastern Canada, bird rape supplants *S. arvensis* over large areas. Alex and Switzer (1976) indicate it occurs in a few grainfields and waste areas in Southern Ontario;
- *Brassica napus* (rapeseed) is recorded in the NT-M, LB, NF, PE, NS, NB, PQ, ON, MB, SK, AB and BC. *Brassica napus* is not listed in *Weeds of Canada* (Frankton and Mulligan, 1993) nor in *Ontario Weeds* (Alex and Switzer, 1976).
- *Brassica juncea* (oriental mustard and brown mustard) is recorded in NT-M, NF, NS, PE, NB, PQ, ON, MB, SK, AB and BC. *Weeds of Canada* reports that it occurs in every province and reaches its greatest abundance in the western provinces. *Ontario Weeds* indicates its distribution is similar to that of *S. arvensis* although it is generally less common;
- *Brassica nigra* (black mustard) is recorded in NF, NS, PE, NB, PQ, ON, SK, and BC. *Weeds of Canada* suggests that it is not very common in western Canada. In *Ontario Weeds* it is listed as occurring in a few localities in the south of the province especially in fields and waste areas bordering river valleys, and along railways;
- *Diplotaxis muralis* (sand rocket) is recorded in NS, PE, NB, PQ, ON, MB, SK, and AB. *Weeds of Canada* does not list this species. *Ontario Weeds* indicates it usually occurs in coarse soils along roads, railways, beaches and around buildings and waste places in southern Ontario;

- *Diplotaxis tenuifolia* (wall rocket) is recorded in NS, NB, PQ, and ON. It is a common perennial found along roadsides and in waste places (Crompton *et al.*, 1988). *Weeds of Canada* does not list this species.
- *Erucastrum gallicum* is recorded in NT-M (Warwick and Wall, 1998), NF, NS, PE, NB, PQ, ON, MB, SK, AB and BC. *Weeds of Canada* states that it reaches its greatest abundance in Manitoba and Saskatchewan where it inhabits fields, waste places, railway yards, gardens, and orchards. It is very common on roadsides, and is an abundant field weed in many localities in Western Canada. In Ontario, it occurs throughout the province but is more common in southern Ontario where it is frequently found around railway yards, waste places, orchards, gardens, roadsides and occasionally in grainfields;
- *Raphanus sativus* (radish) is recorded in NT-F, NF, NS, PE, NB, PQ, ON, MB, SK, AB and BC. *Weeds of Canada* indicates that this species is occasionally persistent in gardens (as a result of cultivation) and in wild locations;
- *Sinapis arvensis* (wild mustard) is recorded in NT-M, YT, LB, NF, NS, PE, NB, PQ, ON, MB, SK, AB and BC. *Weeds of Canada* lists it as one of the most common annual weeds. It occurs in all provinces where the most serious infestations are probably in the rich river valleys of the West. Its habitats include grainfields, cultivated fields, waste places, fence rows and roadsides. *Ontario Weeds* indicates that it occurs throughout Ontario being most frequent in cultivated fields and gardens but occasionally appearing in fence lines, along roadsides and in waste areas.

C4.0 The Agro-Ecology of Weedy Relatives of *B. rapa*

Of the relatives discussed, *S. arvensis* (wild mustard) is listed as a primary noxious weed in the *Weed Seeds Order* (1986) and is potentially the weediest in agricultural crop lands. It is relatively easily controlled in crops of species other than *Brassica* by the use of selective herbicides.

Weed species prominence can be dramatically affected by cropping systems and cultivation practices. The recent adoption of minimum and no till crop production systems, and the abandonment of cultivated summerfallow practices as a means of soil conservation, have caused a shift in the prominence of different weed species.

The weedy relatives of *B. rapa* are all plants of disturbed habitats, and the ecosystems in which they survive and flourish are as described in part C3.0 above. Their success will be dependent on their ability to compete for space with other primary colonizers, in particular, with other successful weedy plant types. This in turn will depend on how well suited they are to the particular climate, soil conditions, etc. of individual sites.

Part D Potential Interactions of *Brassica rapa* with Other Life Forms

Table 2 is intended as an identification guide for categories of organisms interacting with *B. rapa*, to be used by applicants in their consideration of potential impacts of the release of the PNT on non-target organisms.

The intention is not to require comparative data between the PNT and its *B. rapa* counterpart(s) for all interactions. Depending on the novel traits, applicants might decide to submit data for only some of the interactions. Sound scientific rationale will be required to justify the decision that data would be inappropriate or irrelevant for the remaining interactions. For example, the applicant might choose not to provide data on the potential for gene transfer from the PNT to related species if it can be clearly shown that the novel trait will not affect reproductive characteristics of *B. rapa*, either directly or indirectly.

Some of the life forms are listed as categories (i.e. pollinators, mycorrhizal fungi, animal browsers, birds, soil microbes, and soil insects). When, because of the novel traits, a concern is perceived for these specific categories, applicants will be required to provide detailed information on interactions with indicator species in each category. Where the impact of the PNT on another life form (target or non-target organism) is significant, secondary effects may need to be considered.

TABLE 2. Potential interactions of *B. rapa* with other life forms during its life cycle.

“X” indicates the type of interaction between the listed organisms and *B. rapa* (information requirements may be waived if valid scientific rationale is provided).

| Interaction with <i>B. rapa</i> | | | | |
|---|----------|---------------------------------|----------|---------------|
| Other life forms | Pathogen | Symbiont or Beneficial Organism | Consumer | Gene transfer |
| <i>Albugo candida</i> - white rust | X | | | |
| <i>Alternaria spp.</i> - black spot | X | | | |
| <i>Botrytis cinerea</i> -gray mold | X | | | |
| <i>Erysiphe spp.</i> - powdery mildew | X | | | |
| <i>Leptosphaeria maculans</i> - blackleg | X | | | |
| <i>Peronospora parasitica</i> - downy mildew | X | | | |
| <i>Plasmodiophora brassicae</i> -club root | X | | | |
| <i>Pyrenopeziza brassicae</i> - light leaf spot | X | | | |
| <i>Pythium debaryanum</i> - damping off | X | | | |
| <i>Rhizoctonia solani</i> - basal stem rot, damping off | X | | | |
| <i>Sclerotinia sclerotiorum</i> - sclerotinia stem rot | X | | | |
| <i>Xanthomonas spp.</i> - bacterial rot | X | | | |
| Turnip mosaic virus | X | | | |
| Aster yellows mycoplasma | X | | | |
| Flea beetle | | | X | |
| Pollinators | | X | X | |
| Mychorrhizal fungi | | X | | |
| Birds | | | X | |
| Animal browsers | | | X | |
| Soil microbes | | X | | |
| Earthworms | | X | | |
| Soil insects | | | X | |
| Other <i>Brassica rapa</i> | | | | X |
| <i>Brassica napus</i> | | | | X |
| <i>Brassica juncea</i> | | | | X |
| <i>Brassica nigra</i> | | | | X |
| <i>Raphanus sativus</i> | | | | X |
| <i>Sinapis arvensis</i> | | | | X |
| <i>Diplotaxis eruroides</i> | | | | X |
| <i>Diplotaxis muralis</i> | | | | X |
| <i>Diplotaxis tenuifolia</i> | | | | X |
| <i>Erucastrum gallicum</i> | | | | X |
| Others | | | | |

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