Canadian Food Inspection Agency

The Biology of *Camelina sativa* (L.) Crantz (Camelina)

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A companion document to Directive 94-08 (Dir94-08), Assessment Criteria for Determining Environmental Safety of Plant with Novel Traits

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General Administrative Information

1.1 Background

The Canadian Food Inspection Agency's Plant and Biotechnology Risk Assessment (PBRA) Unit is responsible for assessing the potential risk to the environment from the release of plants with novel traits (PNTs) into the Canadian environment. The PBRA Unit is also responsible for assessing the pest potential of plants imports and plant species new to Canada.

Risk assessments conducted by the PBRA Unit require biological information about the plant species being assessed. Therefore, these assessments can be done in conjunction with species-specific biology documents that provide the necessary biological information. When a PNT is assessed, these biology documents serve as companion documents to **Dir94-08: *Assessment Criteria for Determining Environmental Safety of Plants with Novel Traits***.

1.2 Scope

This document is intended to provide background information on the biology of *Camelina sativa*, its identity, geographical distribution, reproductive biology, related species, the potential for gene introgression from *C. sativa* into relatives, and details of the life forms with which it interacts.

Such information will be used during risk assessments conducted by the PBRA Unit. Specifically, it may be used to characterize the potential risk from the release of the plant into the Canadian environment with regard to weediness/invasiveness, gene flow, plant pest properties, impacts on other organisms and impact on biodiversity.

2 Identity

2.1 Name(s)

Camelina sativa (L.) Crantz

2.2 Family

Brassicaceae (Cruciferae) family, commonly known as the mustard family.

2.3 Synonym(s)

Synonyms for *Camelina sativa* are *C. parodii* Ibara & La Porte, *Myagrum sativum* L. (basionym), *C. caucasica* (Sinskaya) Vassilcz, and *C. glabrata* (DC.) Fritsch ex N.W. Zinger (Francis and Warwick 2009; USDA, ARS 2011).

2.4 Common name(s)

Camelina sativa is commonly known as gold-of-pleasure, false flax, big-seed false flax, large-seeded false flax, Dutch flax, western false flax, wild flax (UK), German sesame, linseed dodder, caméline ciliée, Leindotter, camelina, camelina pilosa, caméline cultivée, caméline faux-lin, faux lin, faux lin de l'Ouest, lin bâtard, petit lin, sésame bâtard, and sésame d'Allemagne (Putnam et al. 1993; Darbyshire 2003; Francis and Warwick 2009; USDA, ARS 2011).

2.5 Taxonomy and genetics

The genus *Camelina* is a member of the tribe Camelineae of the mustard family (Brassicaceae) (Al-Shehbaz et al. 2006). In addition to *Camelina* spp., the Camelineae tribe includes the model plant *Arabidopsis thaliana* (L.) Heynh. and the weedy species *Capsella bursa pastoris* (L.) Medik.

Genetic mapping of the genome of *C. sativa* suggests a polyploid or duplicated structure (Gehringer et al. 2006; Galasso et al. 2010), and characterization of two genes in the fatty acid biosynthesis pathway further suggests a hexaploid genome (Hutcheon et al. 2010). Chromosome counts have been reported as n=6 or 14 or 2n=12, 26 or 40, with 2n=40 being the most common count (Warwick et al. 1999; Mulligan 2002; Gehringer et al. 2006).

Taxonomic position (USDA, NRCS 2010):

Kingdom: Plantae (plants)
Subkingdom: Tracheobionta (vascular plants)
Superdivision: Spermatophyta (seed plants)
Division: Magnoliophyta (flowering plants)
Class: Magnoliopsida (dicotyledons)
Subclass: Dilleniidae
Order: Capparales
Family: Brassicaceae (mustard family)
Tribe: Camelineae
Genus: *Camelina* Crantz (false flax)
Species: *Camelina sativa* (L.) Crantz (gold-of-pleasure)

2.6 General description

Camelina sativa is a herbaceous annual or winter annual with a taproot. Plants are erect and typically reach heights between 30 and 90 cm (Putnam et al. 1993; Francis and Warwick 2009). Rosette leaves are not lobed and are withered at flowering (Francis and Warwick 2009). Leaves on stems are alternate, lance-shaped, lacking a petiole, and usually clasping. They are typically 2 to 8 cm long and 2 to 10 mm wide and may be smooth or have a few, primarily forked, hairs (Francis and Warwick 2009). Stems are single, typically branched above, and become woody as they mature. Stems may be smooth or may be sparsely hairy (Putnam et al. 1993; Francis and Warwick 2009). Flowers are small and pale yellow or greenish-yellow in colour. The four petals are spatulate, 4 to 5 mm in length, the four sepals are erect and the six stamens are in three pairs of unequal length (Francis and Warwick 2009). Inflorescences are racemes with the flowers in terminal clusters and lack bracts (Francis and Warwick 2009). The pear-shaped silicles are smooth and leathery, 7 to 9 mm long and superfically resemble the bolls of flax (Francis and Warwick 2009). Seeds are small, pale yellow-brown, generally 2 to 3 mm long, and are rough, having a deeply ridged surface (Putnam et al. 1993; Francis and Warwick 2009). Seeds typically contain 38 to 43% oil and 27 to 32% protein (Gugel and Falk 2006).

Camelina sativa closely resembles two congeners also found in Canada, *C. microcarpa Andrz.* ex DC. and *C. alyssum* (Mill.) Thell. Generally, *C. microcarpa* stems are hairier than those of *C. sativa*, and the leaves on the stems are pubescent primarily with simple trichomes (Al-Shehbaz and Beilstein 2010). *Camelina microcarpa* can be further differentiated from *C. sativa* by the size of both silicles and seeds, which are 5 to 7 mm and 0.8 to 1.4 mm long, respectively, for *C. microcarpa* (Francis and Warwick 2009). *Camelina sativa* may be distinguished from *C. alyssum* based on the leaves, which for *C. alyssum* are deeply toothed or lobed, while for *C. sativa* they are only shallowly toothed. In addition, *C. alyssum* silicles are shaped as a flattened sphere as opposed to the pear-shaped silicles of *C. sativa* (Francis and Warwick 2009).

Photo Credit: K. Topinka, University of Alberta

3 Geographical Distribution

3.1 Origin and history of introduction

Camelina spp. likely originated in southeastern Europe and southwestern Asia (Francis and Warwick 2009), although the exact region remains uncertain. A molecular analysis of a number of *C. sativa* accessions of Russian-Ukrainian origin revealed that this region is a hotspot for genetic diversity in *C. sativa*, suggesting that it could be the centre of origin for this species (Ghamkhar et al. 2010).

Archaeological evidence suggests that the cultivation of camelina began in Neolithic times in southeast Europe, and by the Iron Age camelina was an important crop throughout most of Europe (Knörzer 1978). Cultivation declined during the Middle Ages (Knörzer 1978), but is still reported as late as the middle of the 20th century (Zubr 1997).

Camelina was likely introduced to North America as a contaminant in seeds of flax or other crops (Putnam et al. 1993; Francis and Warwick 2009). In Canada, camelina was first reported in Manitoba in 1863, where it was deliberately introduced, and subsequently it has been found as far west as the Peace River District and as far north as the Northwest Territories by the early to mid-1900s (Francis and Warwick 2009). Camelina has periodically been considered as a potential crop in North America (Porcher 1863; Plessers et al. 1962; Downey 1971; Robinson 1987), but although cultivation on a small scale has been ongoing for some time, significant commercial cultivation began only in the late 1990s.

3.2 Native range

Europe	Albania, Austria, Belarus, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France (including Corsica), Germany, Greece (including Crete), Hungary, Italy (including Sardinia, Sicily), Latvia, Lithuania, Moldova, The Netherlands, Norway, Poland, Romania, Russian Federation, Slovakia, Slovenia, Sweden, Switzerland, Ukraine, United Kingdom (Global Invasive Species Database 2010; USDA, ARS 2011).
Asia	Armenia, Azerbaijan, China (Nei Monggol, Xinjiang), Georgia, Kazakhstan, Mongolia, Russian Federation, Turkey (Global Invasive Species Database

2010; USDA, ARS 2011).

3.3 Introduced range

Australia	*Camelina sativa* has been reported in southern and western Australia (Barker et al. 2005; Western Australian Herbarium 2010).
Canada	*Camelina sativa* can primarily be found in the four western provinces in Canada, although it has also been reported in all of the other provinces except Newfoundland. Camelina sativa has also been reported in Yukon and the Northwest Territories but not Nunavut (Francis and Warwick 2009; Government of Canada 2011).
Chile	(Francis and Warwick 2009).
Ireland	*Camelina sativa* is reported to be rare in Ireland (Milbau and Stout 2008).
Japan	*Camelina sativa* is recognized as an alien species in Japan that is established or found in the wild (Mito and Uesugi 2004).
Mexico	*Camelina sativa* has been reported in 3 of 32 Mexican states (Villaseñor and Espinosa-García 2004).
New Zealand	*Camelina sativa* is listed as a naturalised plant in New Zealand (Webb et al. 1988; Francis and Warwick 2009).
United States	*Camelina sativa* is widespread in the United States and can be found in 38 states. There have been no reports to date for California, Nevada, Colorado, Texas, Indiana, Arkansas, Mississippi, Tennessee, Alabama, Georgia, Florida, or Hawaii (USDA, ARS 2011).

3.4 Potential range in North America

Camelina sativa has been reported to NAPPFAST Plant Hardiness Zones 1 through 9 (Magarey et al. 2008; map at **NAPPFAST Global Plant Hardiness Maps**). This suggests that the potential range of *C. sativa* includes most or all of North America.

3.5 Habitat

Camelina sativa can be found growing in natural prairies, grain, flax and alfalfa fields, open woods, lakeshore, roadsides, railways, and waste places as well as around elevators (Scoggan 1978; Warwick et al. 1999; Mulligan 2002). Camelina grows best in cold semi-arid climate zones in steppes or prairies (Francis and Warwick 2009). It is able to grow in most soil types (Porcher 1863; Anderson and Olsson 1950; Gugel and Falk 2006).

When cultivated on marginal lands, Camelina is generally reported to grow well (Porcher 1863; Putnam et al. 1993; Gehringer et al. 2006; Ehrensing and Guy 2008). In particular, camelina can tolerate drought conditions (Zubr 1997; Gugel and Falk 2006; Francis and Warwick 2009), although severe droughts, particularly during sensitive growth stages such as flowering can have a negative impact (Vollmann et al. 1996). Camelina shows some cold tolerance in that it is able to germinate at low temperatures and seedlings are able to tolerate frost (Plessers et al. 1962; Robinson 1987; Putnam et al. 1993; Ehrensing and Guy 2008), although this has not been fully characterized. For some varieties, seedlings have been observed to survive temperatures as low as -11°C without damage (Plessers et al. 1962; Ehrensing and Guy 2008). A comparison of several growth parameters for camelina and canola under varying saline concentrations revealed that camelina does not perform as well as *Brassica napus* L. under moderate to high saline levels (Stepphuhn et al. 2010); however, only a single variety of camelina was tested, and therefore other varieties with greater salt tolerance may exist.

4 Biology

4.1 Reproductive biology

Camelina reproduces by means of seed and does not exhibit any vegetative reproduction (Francis and Warwick 2009). Rates of outcrossing for camelina have not been documented. Camelina is reported to be primarily self-pollinating (Plessers et al. 1962; Zubr 1997; Mulligan 2002), but cross-pollination mediated by insects, and in particular bees, has also been suggested (Blamey and Grey-Wilson 1989; Corbet et al. 1991; Milbau and Stout 2008). A study conducted in Sweden measured the quantitative distribution of the worker bumblebee (*Bombus* spp.) population on different agricultural crops and found that camelina was visited by bumblebees at a frequency similar to flax (*Linum usitatissimum* L.) and rapeseed (*Brassica napus* var. *oleifera*) (Fridén 1972).

The flowering and pollination of camelina have been described by Tedin (1922) and Schultze-Motel (1939). The flowers are reported to be protogynous and may open at different hours throughout the day, but the majority open by mid-morning. One to two hours prior to the opening of the flower, the anthers are ripe, although they may open only when the flower does. Once the flower does open, the four longer stamens have reached the same height as the stigma, and the anthers have burst open. The anthers on the two shorter stamens will open only a few hours after the flowers open. At night, the closing of the flower causes the inner anthers of the four longer stamens to press against the stigma. At this point, the anthers have less pollen but are not yet empty. The next day, the flower will open again. The anthers on the longer stamens will be empty, while those on the two shorter stamens may still contain some pollen. On this second day, the petals will begin to wilt and after another two to three days both petals and sepals will fall off.

4.2 Breeding and seed production

Given the sporadic, low level cultivation of camelina that has occurred in North America in the past, there has been little interest in camelina breeding until recently. The observed variability in the crop suggests that it can be improved through breeding (Budin et al. 1995; Vollmann et al. 1996; Schuster and Friedt 1998; Gehringer et al. 2006; Vollmann et al. 2007).

Some of the key traits that are the focus of camelina breeding, which we can expect to see in Canadian germplasm in the future, include the improvement of quality traits, agronomic performance, and in some instances disease resistance. Quality traits include increased seed size, increased oil content, modified oil composition and decreased levels of anti-nutrients such as erucic acid and glucosinolates (Vollmann et al. 1996; Büchsenschütz-Nothdurft et al. 1998; Zubr 2003a; Vollmann et al. 2005; Gehringer et al. 2006; Pilgeram et al. 2007; Vollmann et al. 2007). Modifications to the fatty acid profile will likely depend on the desired end use of the oil (Putnam et al. 1993; Pilgeram et al. 2007). For use as a lubricant, higher levels of hydroxy fatty acids will be favoured. For food uses, increased levels of α-linolenic acid may be favoured to increase nutritive value. Alternatively, decreased levels of α-linolenic acid and other unsaturated fatty acids may be favoured to improve the oxidative stability of the oil. Increases in antioxidants, such as γ-tocopherol, could also help to improve the stability of the oil. Agronomic performance traits that will be targeted include increased seed size, resistance to lodging, increased competitive ability (e.g., broader leaves), and herbicide resistance (Zubr 1997; Zubr 2003a; Pilgeram et al. 2007). Disease resistance breeding will likely include resistance to downy mildew (*Peronospora parasitica* (Pers.:Fr.) Fr.), white rust (*Albugo candida* (Pers.) Kuntze), and sclerotinia stem rot (*Sclerotinia sclerotiorum* (Lib.) de Bary) (Vollmann et al. 2001; Zubr 2003a; Pilgeram et al. 2007).

While many breeding efforts are employing conventional crossing to develop camelina, genetic mapping of camelina has also begun for molecular breeding (Vollmann et al. 2005; Gehringer et al. 2006). Mutational breeding of camelina is also being explored (Vollmann et al. 1997; Büchsenschütz-Nothdurft et al. 1998). More recently, genetic engineering of camelina plants has been reported (Lu and Kang 2008) for the purpose of producing novel fatty acids as well as other biochemicals such as bioplastics, primarily for industrial applications.

Currently, in Canada, camelina seeds do not require variety registration. Varietal purity standards for pedigreed seed crop production of Foundation, Registered and Certified seed have been developed by the Canadian Seed Growers' Association (Canadian Seed Growers' Association 2010).

4.3 Cultivation and use as a crop

Camelina is usually seeded in the spring (Gugel and Falk 2006; Urbaniak et al. 2008b). Winter seeding is also being investigated (Robinson 1987; Putnam et al. 1993), although it is unclear at this time if this will be a common practice. Seeds are planted at a shallow depth with good soil contact (Putnam et al. 1993; McVay and Lamb 2007; Ehrensing and Guy 2008). Seeds can be drilled using packer wheels to achieve this, or if broadcast, a roller harrow can be used to mix seed and soil together (McVay and Lamb 2007). Use of both a seed drill and a forage seeder to sow camelina were found to provide good crop establishment, but the forage seeder provided a better crop stand compared to the seed drill (Urbaniak et al. 2008b). Generally, the seeding and harvesting equipment used for canola and mustard crops are suitable for camelina (Gugel and Falk 2006).

The recommended sowing rate ranges from 3 to 7 kg/ha (approximately 250 to 600 seeds/ m^2), with the objective of producing a stand density in the range of 125 to 200 plants/m^2 (Zubr 1997; McVay and Lamb 2007; Johnson et al. 2008; Urbaniak et al. 2008b; Johnson et al. 2011). Higher seeding rates can increase the competitiveness of the crop and decrease time to maturity (Johnson et al. 2008, 2011). The rate of emergence for camelina has been observed to range from 12% to 70%, with an average of approximately 40%, which is comparable to canola (Thomas 2003; Johnson et al. 2007, 2008; Urbaniak et al. 2008a; Urbaniak et al. 2008b; Johnson et al. 2011). As with other brassicas, it is generally recommended that camelina not be grown in a field more than once every three to four years (McVay and Lamb 2007; Ehrensing and Guy 2008). In semi-arid wheat growing regions of the Great Plains, camelina could potentially replace fallow periods in typical small grains rotations (Lafferty et al. 2009). Due to its short growing season, camelina also has the potential to be incorporated into double cropping systems, particularly in warmer climates (Putnam et al. 1993).

While it has been suggested that camelina can grow without fertilizer application, this will ultimately depend on the nutrient levels in the soil. Studies have shown that yield is improved through the application of nitrogen and the recommended application rate ranges from 60 to 100 kg N ha^{-1} (Zubr 1997; Crowley and Fröhlich 1998; Ehrensing and Guy 2008; Johnson et al. 2008; Urbaniak et al. 2008a; Johnson et al. 2011). Depending on soil levels, application of phosphorous and sulphur may also improve yield (Jackson 2008); however, at this time the optimal application rate has not been determined. In the absence of this information, fertilizer application for camelina may be modelled after canola production practices.

Weed control for camelina may be challenging due to its sensitivity to most herbicides. Camelina does show tolerance to the Group I acetyl CoA carboxylase (ACCase) inhibitors and dinitroaniline herbicides, such as ethalfluralin, pendimethalin and trifluralin (Johnson et al. 2007, 2008, 2011). In Canada, Assure® II (quizalofop-p-ethyl) has received a User Requested Minor Use Label Expansion for the control of annual and perennial grasses in camelina. A minor use label expansion is also currently being sought for Roundup (glyphosate) for pre-harvest weed control. In the United States, Poast® (sethoxydim) has been registered for use on camelina, also for the control of grass weeds.

Pre-seeding tillage is a means of weed control. However, it has been suggested that camelina shows good weed competitiveness, especially when plant stands are dense, although this has not been directly measured. This may in part be due to the early emergence and rapid growth of this crop, as well as its cold tolerance, which allows it to be planted early (Putnam et al. 1993; Ehrensing and Guy

2008). As a result, it may be possible to grow camelina with minimal tillage and pre-emergence weed control (Putnam et al. 1993). If weeds are problematic, the best weed control practices will include the selection of fields that do not have a high weed pressure, establishment of dense, uniform stands, and if necessary, the use of fallow techniques (McVay and Lamb 2007).

The seeds of weeds such as prickly lettuce (*Lactuca serriola* L.), stinkweed (*Thlaspi arvense* L.) and shepherd's purse (*Capsella bursa pastoris*) are difficult to separate from camelina seeds due to similarities in size and could result in downgrading for pedigreed seed crops (Canadian Seed Growers' Association 2010). Other weeds that could be problematic include *Kochia scoparia* (L.) Schrad. as well as volunteer canola plants. Overall, broadleaf weeds are likely to be the most difficult to control during cultivation.

Few problems with insect infestations have been reported and therefore insect control measures are not usually undertaken (Robinson 1987; Zubr 1997; Gugel and Falk 2006; Ehrensing and Guy 2008).

Camelina is a short-season crop that matures in 85 to 100 days (Putnam et al. 1993; Gugel and Falk 2006; Ehrensing and Guy 2008). Camelina can be swathed for field drying prior to harvest, or it can be direct combined if varieties that are resistant to shattering are used (Zubr 1997; McVay and Lamb 2007; Pilgeram et al. 2007; Ehrensing and Guy 2008). Swathing is recommended if there is a high degree of lodging or green weeds in the field (McVay and Lamb 2007). Swathing should be done when two-thirds of the pods turn from green to yellow (Ehrensing and Guy 2008). Although it is recommended to harvest camelina immediately, at least one study has demonstrated that there is no loss of yield if the crop is left to stand up to a month after maturity (Crowley and Fröhlich 1998).

Historically, camelina has been cultivated as a source of food and animal feed. In addition, the oil has been used as lamp fuel as well as in various industrial applications and the stems were valued for their fibre (Porcher 1863; Sturtevant 1919; Francis and Warwick 2009).

Currently, camelina oil is being used as a feedstock for the production of biofuel (McVay and Lamb 2007; El Bassam 2010). The primary market for the biofuel includes the commercial airline industry as well as the military. A number of other industrial uses for camelina oil have been proposed, including use in paints, inks, soaps, varnishes, lubricants, cosmetics and as a plastic additive (Bonjean and Le Goffic 1999; McVay and Lamb 2007; Pilgeram et al. 2007; El Bassam 2010).

Due to high levels of essential fatty acids, particularly the omega-3 fatty acid α-linolenic acid, camelina oil is also being investigated as a food ingredient (Ní Eidhin et al. 2003; Zubr 2003b; Abramovic and Abram 2005; Ní Eidhin and O'Beirne 2010). In 2010, Health Canada approved the use of cold-pressed, unrefined camelina oil as a food ingredient in Canada. In some eastern European countries, camelina oil is used in folk medicine for the treatment of burns, wounds, eye inflammations, as well as to cure stomach ulcers and as a tonic (Rode 2002).

Several studies have demonstrated the applicability of using camelina meal as a feed component for broiler and laying chickens, beef and dairy cattle, and fish such as salmon, with the added benefit of increasing the omega-3 content of the resulting meat, eggs and dairy products (McVay and Lamb 2007; Peiretti and Meineri 2007; Pilgeram et al. 2007; Aziza et al. 2010; Bell et al. 2010). The U.S. Food and Drug Administration has approved the use of camelina meal for up to 10% of the diet of cattle fed in confinement for slaughter, broiler chickens and laying hens. They have also approved camelina meal for up to 2% of the diet of growing swine. Camelina meal has not yet been approved for use as animal feed in Canada.

4.4 Gene flow during commercial seed and biomass production

There is no information available about the potential for gene flow from camelina during cultivation to wild relatives, including other *Camelina* species.

4.5 Cultivated *Camelina sativa* as a volunteer weed

As with all crops, some camelina seed will be lost during harvest, remaining in the field to become volunteers in subsequent crops. However, it is likely that any volunteers can be easily controlled. In one report, camelina volunteers were never observed to be a problem in over thirty years of field research (Robinson 1987).

Shattering could contribute to harvest losses (Plessers et al. 1962), but to date shattering losses have been reported to be low (Gugel and Falk 2006; Johnson et al. 2007; Ehrensing and Guy 2008). The small seed size of camelina may also contribute to harvest losses.

Cultivated camelina seeds are reported to show no dormancy (Robinson 1987; Ehrensing and Guy 2008).

Variable results have been observed in seed burial experiments, and it remains unclear how long camelina seeds will persist in the seed bank. In Saskatchewan, camelina seeds distributed throughout a 2.5 inch layer of soil and buried in November did not germinate until the subsequent spring, at which point almost all of the seeds germinated during the month of April (Chepil 1946). In a burial experiment conducted in southeastern France using wild camelina seeds, after two and a half years buried at a 10 cm depth, 85.8% of camelina seeds had survived (Saatkamp et al. 2009). Therefore, under some conditions it is possible that camelina seeds may persist in the seed bank.

It is likely that the majority of camelina seeds will germinate a few weeks after the first significant rainfall provided there is good soil contact (McVay and Lamb 2007). This suggests that most camelina seeds lost during harvest will likely germinate in the fall; however, some seeds may persist in the seed bank. Due to their frost tolerance, seedlings that germinate in the fall could potentially survive until the following season, depending on the climatic conditions in the area where they are growing.

4.5.1 Cultural/mechanical control

In order to minimize the number of potential camelina volunteers, efforts should be made to reduce harvest losses. This can be done by properly setting combines and sealing any leaks.

4.5.2 Chemical control

Due to the high sensitivity of camelina to most herbicides, volunteers can be easily controlled by herbicides. The group 4 herbicides 2,4-dichlorophenoxyacetic acid (2,4-D) and 2-methyl-4-chlorophenoxyacetic acid (MCPA) are registered for the control of camelina weeds. Chemical fallow systems have also been used in the fall (McVay and Lamb 2007).

4.5.3 Integrated weed management

Integrated weed management (IWM) employs a combination of cultural, mechanical and chemical weed control approaches to manage weed populations and maximize crop yields. IWM strategies have not yet been developed for the control of camelina volunteers, but it is likely that such an approach will be useful. Practices such as early seeding, increased seeding rates, and use of competitive cultivars will be applicable..

4.5.4 Biological control

Biological control methods for camelina volunteers have not been developed.

4.6 Means of movement and dispersal

The means of movement and dispersal of camelina seeds are unclear at this time. Camelina seeds might be dispersed by organisms that consume the seeds. In Ireland, birds have been observed to eat camelina seeds (Crowley and Fröhlich 1998). Similarly, in northern Switzerland, slugs were found to consume camelina seeds, and germinating seeds were sometimes observed in slug feces (Kollmann and Bassin 2001).

Davis (2010) demonstrated that the risk of establishment of camelina in rangeland ecosystems in southwest Montana was low. Camelina plants were found to survive to establishment only in plots that were subjected to mechanical disturbance. Therefore, although camelina seeds may be dispersed from the site of cultivation, their ability to become established may depend upon the receiving environment.

5 Related Species of *Camelina sativa*

Camelina sativa is able to interbreed with its congeners in the *Camelina* genus. In addition to *C. sativa*, *C. microcarpa*. and *C. alyssum* are also present in Canada and the United States while *C. rumelica* Velen. can be found in the United States, but has not been observed in Canada (USDA, NRCS 2010). *Camelina alyssum* is not very widespread in Canada, having been found only in the provinces of Alberta, Saskatchewan and Manitoba where it was identified in prairie fields and on roadsides (Warwick et al. 1999; Francis and Warwick 2009). In contrast, *C. microcarpa* has been found in all of the provinces as well as Yukon (Warwick et al. 1999; Francis and Warwick 2009). Much like *C. sativa*, *C. microcarpa* can be found growing in grain, flax, corn and hay fields, prairies, pastures, grasslands, rangeland, low slopes, flats and sloughs as well as along roadsides, railways and wharves and in waste places (Warwick et al. 1999).

Outside of the *Camelina* genus, other species closely related to camelina with the potential to interbreed can be found within the *Camelineae* tribe. Those found in Canada include *Arabidopsis lyrata* L. and *A. thaliana*, *Capsella bursa pastoris*, *Neslia paniculata* (L.) Desv., *Erysimum* spp., and *Turritis glabra* L. The following details the distribution and habitat for each of these species in Canada, according to Warwick et al. (1999).

Arabidopsis lyrata can be found in the Northwest Territories, British Columbia, the three Prairie Provinces, Ontario and Quebec. It grows on dry to moist wooded hillsides, rocky ledges, cliffs and islets, thickets, woods, banks, beaches, dunes, and shores of streams, rivers and lakes.

Arabidopsis thaliana has been found in British Columbia, Ontario and Quebec. It grows on open slopes and in woods, gardens, fields, meadows and banks. It can also be found on alkaline flats, flood plains, sloughs, beaches and shores, beside roads, railways and in waste places.

Capsella bursa pastoris can be found in every province and territory in Canada. It grows in grain, hay, canola, potato and strawberry fields, pastures, meadows, orchards, vineyards, gardens, woods, flats, beaches and hotsprings. It can also be found around docks, fish houses and beside roads, railways and in waste places.

Neslia paniculata is found throughout Canada except for Nunavut and Labrador. It can be found growing in grain, alfalfa and potato fields, wooded areas that have been cut-over, and gardens as well as roadsides, railways, waste places and near elevators.

Ten *Erysimum* spp. have been found growing in Canada. Several have a limited distribution, including *E. angustatum* Rydb., found only in Yukon, *E. arenicola* S. Watson and E. *capitatum* (Douglas ex Hook.) Greene, both found only in British Columbia, and *E. pallasii* (Pursh) Fernald (purple rocket), found in the three Territories as well as British Columbia and Alberta. All four species grow primarily in arctic and/or alpine habitats and are therefore unlikely to be found growing near *C. sativa*, with the possible exception of *E. capitatum*, which Darbyshire (2003) reports as a rare agricultural weed in Canada. *Erysimum repandum* L. similarly has a limited distribution, being found only in British Columbia, Ontario and Quebec, where it grows on farms and on lakeshores. *Erysimum asperum* (Nutt.) DC. (western wallflower) can be found from British Columbia to Quebec on hillsides, sandhills, dunes and riverbanks, in shortgrass prairies, rangelands, and by roads as well as in rocky places and on sandstone cliffs. *Erysimum cheiranthoides* L. (wormseed mustard) can be found throughout Canada, except for Nunavut and Labrador, and grows in grain, potato, mustard, and clover fields, prairies, woods, flats and sloughs and on hillsides, cliffs and shores and is often found beside elevators and in waste places. *Erysimum coarctatum* Fernald has been found in Yukon, the Northwest Territories, British Columbia, Alberta, Ontario, Quebec and Newfoundland and grows on slopes, sandbanks and along railways as well as on disturbed calcareous cliffs and gravels. *Erysimum hieracifolium* L. (grey rocket) can be found growing in Saskatchewan, Alberta, Ontario, Quebec, New Brunswick, Nova Scotia and Newfoundland. It grows in pastures, fields, dumpsites, and locks and on river banks as well as on gypsum slopes, by roads and railways and in waste places. *Erysimum inconspicuum* (S. Watson) MacMill. (small-flowered prairie-rocket) has been found from British Columbia to Quebec, New Brunswick and Nova Scotia. It grows on dry slopes, ridges, benches, streambeds, lake margins, banks, and flats, in prairies, grasslands, open woods, pastures, sagebrush, fields and burrows, and by roads and railways.

Turritis glabra has been identified in Yukon, British Columbia, the Prairie Provinces, Ontario, Quebec and New Brunswick. It is typically found growing in crop fields, gardens, pastures, grasslands, woods, thickets, meadows, streamsides and on slopes, banks, bluffs, and cliffs. It has also been found on roadsides and in waste places.

Other members of the Brassicaceae family outside of the Camelineae tribe are more distantly related to camelina and are therefore less likely to be able to interbreed. However, several members of the Brassicaceae family, due to their importance and abundance as agricultural crops in Canada, require further consideration. These include *Brassica napus* (oilseed rape, canola, rapeseed), *B. rapa* L. (turnip rape, bird-rape, canola, rapeseed, turnip), *B. oleracea* L. (cabbage, broccoli, cauliflower), *B. juncea* (L.) Czern. (canola, oriental and brown mustard), *Sinapis alba* L. (white/yellow mustard), and *Raphanus sativus* L. (radish). Wild or feral populations of these species can also be found growing throughout Canada. The following details the distribution and habitat for each of these species in Canada, according to Warwick et al. (1999).

Brassica napus can be found growing throughout Canada except for Yukon and Nunavut. It grows in cultivated and abandoned wheat, oat, potato and rape fields, orchards as well as beside roads and railways, in waste places and near elevators.

Brassica rapa is also found throughout Canada except for Nunavut. It can be found growing in grain, hay, mustard, vegetable, potato, corn, bulb and sugar beet fields, in open woods, meadows, ballast, on riverbanks, slopes and beaches as well as by roads and in waste places.

Brassica oleracea is a rare escape from cultivation that has been found growing in British Columbia, established around driftwood, as well as in Alberta, Ontario, Quebec and Prince Edward Island. It is found mainly in fields, beside roads and in waste places.

Brassica juncea has been found throughout Canada except for Yukon, Nunavut and Labrador. It is typically found in cultivated wheat, oat, potato and rape fields, and orchards, as well as by roads and railways, in waste places, and near feedmills and elevators.

Sinapis alba is again quite widespread throughout Canada, although it has not been identified in the Northwest Territories, Nunavut, Nova Scotia or Newfoundland. It grows in fields, disturbed prairies, on farms and irrigated land, by roads and railways and in waste places.

Raphanus sativus is found throughout Canada except for Yukon, the Northwest Territories and Labrador. It grows in gardens, grain, canola and corn fields, and orchards, on flats and riverbanks, by wharves and on roadsides.

5.1 Inter-species/genus hybridization

Camelina sativa is thought to intercross with many of its congeners in the *Camelina* genus, in particular *C. microcarpa* and *C. alyssum* (Al-Shehbaz 1987). In addition, while intergeneric crosses have been made between *C. sativa* and its relatives in the *Brassica* genus, all have required human intervention in the form of protoplast fusion. Table 1 summarizes reports of interspecific and intergeneric experimental crosses between *C. sativa* and its relatives. Table 2 summarizes reports of somatic hybridization between *C. sativa* and its relatives.

Table 1. Reports of experimental crosses between Camelina sativa and related species.

Cross Female	Cross Male	Description	References
C. sativa	*C. alyssum*	4 pods developed from 10 pollinations	Tedin 1922

C. sativa	*C. alyssum*	1,273 seeds produced from 578 pollinations	Séguin-Swartz et al. 2010
C. alyssum	*C. sativa*	8 pods developed from 9 pollinations	Tedin 1922
C. alyssum	*C. sativa*	918 seeds produced from 639 pollinations	Séguin-Swartz et al. 2010
C. sativa	*C. microcarpa*	708 seeds produced from 590 pollinations	Séguin-Swartz et al. 2010
C. microcarpa	*C. sativa*	1,233 seeds produced from 608 pollinations	Séguin-Swartz et al. 2010
C. sativa	*C. rumelica*	309 seeds from 245 pollinations; seed was mostly shrivelled and non-viable	Séguin-Swartz et al. 2010
C. rumelica	*C. sativa*	32 seeds from 180 pollinations; seeds were mostly shrivelled and non-viable	Séguin-Swartz et al. 2010
C. sativa	*B. juncea*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
C. sativa	*B. juncea*	No seed recovered from 357 pollinations	Séguin-Swartz 2008
B. juncea	*C. sativa*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
B. juncea	*C. sativa*	No seed recovered from 401 pollinations	Séguin-Swartz 2008
C. sativa	*B. napus*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
C. sativa	*B. napus*	No seed recovered from 467 pollinations	Séguin-Swartz 2008
B. napus	*C. sativa*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
B. napus	*C. sativa*	No seed recovered from 518 pollinations	Séguin-Swartz 2008
C. sativa	*B. rapa*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
C. sativa	*B. rapa*	No seed recovered from 356 pollinations	Séguin-Swartz 2008
B. rapa	*C. sativa*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
B. rapa	*C. sativa*	No seed recovered from 453 pollinations	Séguin-Swartz 2008
C. sativa	*B. nigra*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
B. nigra	*C. sativa*	Unsuccessful	Salisbury 1991 (as cited in FitzJohn et al. 2007)
B. nigra	*C. sativa*	No seed recovered from 1,204 pollinations	Séguin-Swartz, Pers. Comm. 2010

		pollinations	Comm. 2010

Table 2. Reports of somatic hybridization between *Camelina sativa* and related species.

Hybridization	Description	References
C. sativa + *B. carinata*	Polyethylene glycol mediated protoplast fusion; 3 fusions resulted in 227 calli, of which 3 each regenerated a single shoot; in all cases, shoots failed to produce roots capable of withstanding transplantation.	Narasimhulu et al. 1994
C. sativa + *B. napus*	Protoplast electrofusion; callus unable to form shoots.	Müller and Sonntag 2000
C. sativa + *B. napus*	Protoplast electrofusion; from 385 calli, 25 shoots were regenerated, 3 of which were confirmed to be hybrids by SSR analysis; seed set was low for F1 and F2 hybrids as well as for the first generation following a backcross to *B. napus*.	Jiang et al. 2009
C. sativa + *B. oleracea*	Polyethylene glycol-mediated protoplast fusion; 4 fusions resulted in 2,903 calli, of which 14 initiated shoots; no plants survived outside of culture.	Hansen 1998
C. sativa + *B. oleracea*	Polyethylene glycol-mediated protoplast fusion; 3 fusions resulted in 5,158 calli, of which 19 initiated shoots; hybrids showed poor root growth, poor growth in soil and sterile flowers.	Sigareva and Earle 1999

5.2 Potential for introgression of genetic information from *Camelina sativa* into relatives

There is potential for crossing, and therefore gene introgression, from *C. sativa* into its congeners in Canada. *Camelina sativa* and *C. alyssum* (as *C. macrocarpa*) have been reported as completely interfertile (Tedin 1922). Recent experimental crosses performed by Séguin-Swartz et al. (2010) confirmed Tedin's report as well as demonstrated the ability of *C. sativa* and *C. microcarpa* to successfully hybridize. However, at this time, the mophology, fertility and genomic composition of such hybrids have not been described. The transfer of genetic information from *C. sativa* into the fourth North American *Camelina* species, *C. rumelica*, is highly unlikely. *Camelina rumelica* is not found in Canada (USDA, NRCS 2010) and seed obtained from experimental crosses between the progeny of *C. sativa* and *C. rumelica* was mostly shrivelled and non-viable (Séguin-Swartz et al. 2010).

The potential for introgression of genetic information from *C. sativa* into other genera is unknown. Of the species within the *Camelineae* tribe previously mentioned as present in Canada, namely *A. lyrata*, *A. thaliana*, *C. bursa-pastoris*, *Erysimum* spp., *N. paniculata*, and *T. glabra*, no information was found to suggest that these species are capable of crossing with *C. sativa* despite their relatively close phylogenetic relationship.

Sexual crosses between *C. sativa* and several *Brassica* spp. were unsuccessful (Table 1). Fewer pollen grains from *C. sativa* were found on stigma of *B. napus*, *B. juncea*, and *B. rapa* compared to self-pollinations, suggesting that pollen does not readily adhere, and pollen that did adhere had not germinated even 48 hours after pollination (Séguin-Swartz 2008). When *C. sativa* was the female parent, pollen from *B. napus*, *B. juncea*, and *B. rapa* was observed to germinate, but pollen tubes did not extend past the stigmatic tissue to penetrate the ovary (Séguin-Swartz 2008). While there are reports of successful protoplast fusion between *C. sativa* and *B. carinata* (Narasimhulu et al. 1994), *B. napus* (Müller and Sonntag 2000; Jiang et al. 2009), and *B. oleracea* (Hansen 1998; Sigareva and Earle 1999), the resulting hybrids typically lacked vigour. Overall, sexual hybridization between *C. sativa* and *Brassica* spp. in the absence of human mediation is thought to be highly improbable. This is not surprising given the large phylogenetic distance between these species that would likely result in genetic incompatibilities (Hansen 1998).

5.3 Summary of the ecology of relatives of *Camelina sativa*

All three *Camelina* species found in Canada have been considered weedy, found primarily in crop fields, along roadsides and in waste places (Warwick et al. 1999; Darbyshire 2003). In North America, *C. microcarpa* is the most widespread (USDA, NRCS 2010). However, in prairie weed surveys conducted over a thirty year period starting in the 1970s, *Camelina* spp. were not ranked very high, always being below the 100th most common weed, and by the 2000s, when 3806 agricultural fields were surveyed following application of in crop herbicides, they were located in less than 0.1% of agricultural fields surveyed, with an average density of 0.8 plants per square meter in the single occurance fields (Leeson et al. 2005). There was no indication that *Camelina* spp. were increasing in abundance or distribution in agricultural fields. *Camelina* spp. are currently classified as secondary noxious weed seeds on the Weed Seeds Order, 2005, although their removal from the Weed Seeds Order is currently being considered.

An accession of *C. microcarpa* with resistance to ALS-inhibiting herbicides was identified in Dufur, Oregon, in 1998. The plant showed resistance to chlorosulfuron, metsulfuron as well as cross-resistance to other sulfonylurea, sulfonylaminocarbonyl-triazolinone, imidazolinone and triazolopyrimidine herbicies (Hanson et al. 2004). Resistance of this nature could make control of *C. microcarpa* in agricultural settings more challenging, especially in areas where wheat is grown, as these regions rely heavily on ALS-inhibiting herbicides. However, the resistant *C. microcarpa* accession was easily controlled with a mixture of bromoxynil, MCPA and dicamba, indicating that there are herbicide control options that remain (Hanson et al. 2004). Herbicide mixes and rotation strategies can be applied to limit the development of herbicide resistance (Martin et al. 2001).

Outside of the *Camelina* genus within the *Camelineae* tribe, *C. bursa-pastoris* and *N. paniculata* are the weediest species as well as several of the *Erysimum* spp., in particular *E. cheiranthoides*, *E. asperum* and *E. inconspicuum*. Prairie weed surveys consistently placed *C. bursa-pastoris* among the 25 most abundant species. In the 1990s, it was present in 9.2% of all fields surveyed, averaging 3.3 plants per square meter in occurance fields. *Neslia paniculata* was ranked between the 38th and 61st most abundant weed over the 30 years of the survey (Leeson et al. 2005).

Due to their agricultural importance, crops in the Brassicaceae family are also abundant in Canada. Additionally, several are commonly found growing outside of cultivation, including *B. juncea*, *B. napus*, *B. rapa*, and *R. sativus*. Prairie weed surveys consistently ranked canola/rapeseed (including both *B. napus* and *B. rapa* oilseed cultivars) among the 25 most abundant species (Leeson et al. 2005).

6 Potential Interaction of *Camelina sativa* with Other Life Forms

In general, there appears to be few insect pests of camelina (Robinson 1987; Zubr 1997; McVay and Lamb 2007; Ehrensing and Guy 2008). The crucifer flea beetle (*Phyllotreta cruciferae* Goeze), a common pest of crucifers, does not cause significant damage to camelina, although it may sometimes be observed on camelina plants (Plessers et al. 1962; Putnam et al. 1993; Gugel and Falk 2006; Séguin-Swartz et al. 2010). This appears to be due to the absence of stimulatory cues as opposed to the presence of a repellent (Henderson et al. 2004). Similarly, diamondback moths (*Plutella xylostella* L.), bertha armyworms (*Mamestra configurata* Walker), and crucifer-feeding root maggots (*Delia* spp.) were not found to cause extensive damage to camelina (Séguin-Swartz et al. 2010). The leafhopper *Macrosteles quadrilineatus* Forbes has also been observed among camelina plants, and could potentially serve as a vector for the aster yellows phytoplasma (*Candidatus* Phytoplasma asteris) (Séguin-Swartz et al. 2009).

Camelina also has good resistance to a number of diseases, including the important crucifer diseases black spot (*Alternaria brassicae* (Berk.) Sacc. and *A. brassicicola* (Schwein.) Wiltshire), and blackleg (*Leptosphaeria maculans* (Desmaz.) Ces. & De Not.) (Salisbury 1987; Conn et al. 1988; Sharma et al. 2002; Li et al. 2005; Séguin-Swartz et al. 2009). Resistance to *Alternaria brassicae* is associated with the induction of phytoalexins, namely camalexin and methoxycamalexin (Conn et al. 1998; Browne et al. 1991).

Camelina can, however, be affected by stem rot (*Sclerotinia sclerotiorum*), grey mold (*Botrytis cinerea*

Pers.:Fr.), downy mildew (*Peronospora parasitica*), *Ustilago* spp., white rust (*Albugo candida*), clubroot (*Plasmodiophora brassicae*) and aster yellows. Camelina shows varying degrees of resistance to sclerotinia stem rot, downy mildew and brown girdling root rot, suggesting that resistant cultivars could be developed through breeding (Séguin-Swartz et al. 2009). Diseases of greatest economic importance for the cultivation of camelina appear to be clubroot, white rust, and aster yellows, in part because no resistance has yet been observed in the species (Séguin-Swartz et al. 2009).

It has been suggested that camelina has allelopathic traits. Washings from camelina leaves have been shown to increase radicle length of germinating flax (*Linum usitatissimum*) and wheat (*Triticum aestivum* L.) in the presence of certain bacteria (Lovett and Sagar 1978; Lovett and Jackson 1980). However, Saucke and Ackermann (2006) found that when camelina and peas (*Pisum sativum* L.) were grown together as a mixed crop, there was no evidence for allelopathic traits in camelina. Therefore, there is little evidence to support that camelina possesses allelopathic traits that are effective in the field.

For a list of species associated with camelina, please refer to Table 3.

Table 3. Examples of potential interactions of *Camelina sativa* with other life forms during its life cycle in a natural environment.

Fungi

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Albugo candida (Pers.) Kuntze (white rust)	Pathogen	Present; widespread	Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Botrytis cinerea Pers.:Fr. (grey mold)	Pathogen	Present; widespread	Crowley and Fröhlich 1998; Crowley 1999; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Erysiphe cruciferarum Opiz ex L. Junell (powdery mildew)	Pathogen	Present; widespread	Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Erysiphe polygoni D.C. (powdery mildew)	Pathogen	Present; widespread	Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Fusarium spp. (brown girdling root rot)	Pathogen	Present; widespread	Conners 1967; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009

			2009
Mycosphaerella brassicicola (Duby) Lindau (ringspot of brassicas)	Pathogen	Present; mostly in Prairie Provinces	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Peronospora parasitica (Pers.:Fr.) Fr. (downy mildew; synonym: *Peronospora camelinae* Gäum.)	Pathogen	Present; widespread	Conners 1967; Robinson 1987; Crowley and Fröhlich 1998; Crowley 1999; Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Pseudocercosporella capsellae (Ellis & Everh.) Deighton (grey stem and white leaf spot; teleomorph: *Mycosphaerella capsellae* A.J. Inman & Sivan.)	Pathogen	Present; widespread	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Puccinia aristidae Tracy (rust)	Pathogen	Present; widespread	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Puccinia isiacae (Thün.) G. Winter (rust)	Pathogen	Absent	Séguin-Swartz et al. 2009
Puccinia trabutii Roum & Sacc. (rust)	Pathogen	Absent	Séguin-Swartz et al. 2009
Pyrenopeziza brassicae B. Sutton & Rawl. (light leaf spot; teleomorph: *Cylindrosporium concentricum* Grev.)	Pathogen	Absent	Séguin-Swartz et al. 2009
Pythium debaryanum Auct. non R. Hesse (sore shin, damping-off)	Pathogen	Present; widespread	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Rhizoctonia solani Kühn (sore shin, damping-off, brown girdling root rot; teleomorph: *Thanatephorus cucumeris* (A.B. Frank) Donk)	Pathogen	Present; widespread	Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Sclerotinia sclerotiorum (Lib.) de Bary (sclerotinia stem rot)	Pathogen	Present; widespread	Crowley and Fröhlich 1998; Crowley 1999; Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009

Septoria camelinae Lobik	Pathogen	Absent	Séguin-Swartz et al. 2009
Ustilago spp. (smuts)	Pathogen	Present; widespread	Crowley and Fröhlich 1998; Crowley 1999; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Verticillium longisporum comb. nov. (C. Stark) Karapapa et al. (verticillium wilt)	Pathogen	Absent	Séguin-Swartz et al. 2009

Protist

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Plasmodiophora brassicae Woronin (clubroot)	Pathogen	Present; widespread	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009

Bacteria

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Pseudomonas syringae van Hall pv. spec. (bacterial blight)	Pathogen	Present; widespread	Paul et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Xanthomonas campestris (Pammel) Dowson pv. *Campestris* (black rot)	Pathogen	Present; widespread	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009

Phytoplasma

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Candidatus Phytoplasma asteris (aster yellows)	Pathogen	Present; widespread	Robinson 1987; Paul et al. 2000; Gugel and Falk 2006; Agriculture

(aster yellows)			Falk 2006; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009

Virus

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Beet western yellows virus (BWYV)	Pathogen	Present; British Columbia	Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009
Turnip crinkle virus (TCV)	Pathogen	Absent	Séguin-Swartz et al. 2009
Turnip rosette virus (TRV)	Pathogen	Absent	Séguin-Swartz et al. 2009
Turnip yellow mosaic virus (TYMV)	Pathogen	Present; Ontario	Cerkauskas et al. 1998; Séguin-Swartz et al. 2009

Insects

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Bombus spp. (bumblebees)	Symbiont or benefical organism	Present	Fridén 1972
Ceutorhynchus erysimi F.	Consumer	Present; widespread	Borg 1952; Majka et al. 2007; Entomology Collection 2010
Ceutorhynchus minutus Reich	Consumer	Absent	Ellis 2007
Ceutorhynchus obstrictus Marsham (cabbage seed pod weevil)	Consumer	Present; widespread	Laffin et al. 2005; Cárcamo et al. 2007
Ceutorhynchus quadridens Panz. (cabbage stem weevil)	Consumer	Present	Wahlin 1951; Majka et al. 2007
Ceutorhynchus rapae Gylh. (cabbage curculio)	Consumer	Present; widespread	Borg 1952; Entomology Collection 2010
Ceutorhynchus syrites	Consumer	Absent	Filin'ev 1929;

Ceutorhynchus syrites Germar	Consumer	Absent	Filip'ev 1929; Rakhmaninov and Vuirzhikovskaya 1930; Shapiro 1930; Shapiro 1936; Madel 1950; Dmoch 1968
Delia spp. (root maggots)	Consumer	Present; widespread	CAB International 2007; Andreassen et al. 2010; Séguin-Swartz et al. 2010
Grasshoppers	Consumer	Present; widespread	Davis 2010
Liriomyza xanthocera Czerny	Consumer	Absent	Ellis 2007
Lygus spp.	Consumer	Present; widespread	Kelton 1980; Palagesiu 2000
Macrosteles quadrilineatus Forbes (leafhopper)	Consumer	Present; widespread	Maw et al. 2000; Agriculture and Agri-Food Canada 2007; Séguin-Swartz et al. 2009; Hamilton and Whitcomb 2010; Séguin-Swartz et al. 2010
Mamestra configurata Walker (bertha army worm)	Consumer	Present; widespread in west	Mason et al. 1998; Séguin-Swartz et al. 2010
Meligethes aeneus Fab. (pollen beetle)	Consumer	Unknown	Wahlin 1951; McNamara 1991
Myzus persicae Sulzer (green peach aphid)	Consumer	Present; widespread	Beirne 1972; Commonwealth Institute of Entomology 1979; Séguin-Swartz et al. 2010
Phyllotreta spp. (flea beetles)	Consumer	Present; widespread	Pachagounder et al. 1998; Henderson et al. 2004; Gugel and Falk 2006; Ellis 2007; Entomology Collection 2010; Séguin-Swartz et al. 2010
Plutella xylostella L. (diamondback moth)	Consumer	Present; does not overwinter in Canada; migratory	Harcourt 1957; Harcourt 1963; Deng et al. 2004; Séguin-Swartz et al. 2010
Scaptomyza flava Fallen (leafminer)	Consumer	Absent	Ellis 2007

Animals

	Interaction with C		

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Odocoileus virginianus Zimmerman (white-tailed deer)	Consumer	Yes	Davis 2010
Antilocapra americana Ord (pronghorn antelope)	Consumer	Yes	Pilgeram et al. 2007
Slugs	Consumer	Yes	Kollmann and Bassin 2001
Birds	Consumer	Yes	Crowley and Fröhlich 1998

Plants

Other life forms	Interaction with *C. sativa* (pathogen; symbiont or beneficial organism; consumer; gene transfer)	Presence in Canada	Reference(s)
Camelina microcarpa Andrz. Ex DC.	Gene transfer	Yes	Séguin-Swartz et al. 2010
Camelina alyssum (Mill.) Thell.	Gene transfer	Yes	Séguin-Swartz et al. 2010

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