1 Importance and Origin

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Introduction

Oilseed brassicas, also known by their trade name of rapeseed-mustard, include *Brassica napus*, *B. juncea*, *B. carinata* and three ecotypes of *B. rapa.* In 2012/13 global production of these crops exceeded 63.76 Mt, making them the second most valuable source of vegetable oil in the world. The leading oilseed-brassica producers in the world are the European Union, China, Canada and India (USDA, 2015). Different forms of oilseed brassicas are cultivated throughout the world. Winter-type *B. napus* predominates in Europe, parts of China and eastern USA, while spring-type *B. napus* is cultivated in Canada, Australia and China. Spring forms of *B. rapa* are now mainly grown in the Indian subcontinent. Winter-type *B. rapa* has largely been replaced by more higher yielding winter-type *B. napus* and spring crops in its traditional production zones. Only spring types of *B. juncea* are cultivated in the Indian subcontinent, and is now been actively considered as an option in drier areas of Canada, Australia and even in the northern USA. In India, *B. juncea* predominates and is grown on over 90% of the area under rapeseed-mustard crops. The conventional crop improvement objectives focus largely on attempts to produce, protect and tailor the biomass to suit the main requirement as an edible oil. In some countries of the world, Brassica oil is being used as a biodiesel. The goal of developing canola forms has been accomplished for *B. rapa*, *B. napus* and *B. juncea* but remains an important objective in *B. carinata.* The transition of these crops from high erucic to low erucic rapeseed, and the consequent explosive growth as an oilseed crop, began from Canada in 1968 with the commercial release of single low cv. Oro, followed by several other single low cultivars, and the first canola cv. Tower in 1974. Almost all rapeseed produced in Australia, Canada and Europe and to a very large extent in China, is now canola. The cultivation of canola rapeseed-mustard has just begun in India (Chauhan *et al*., 2010). Further modifications in the acid composition for specialized product applications such as biofuels are being sought.

Brassicas are confronted with several biotic stresses such as diseases (blackleg, Sclerotinia rot, Alternaria blight, white rust, etc.) and pests (aphids, beetles, etc.). As these crops are grown in a wide array of climate and cropping systems, these require general or specific adaptation to

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specific situations. Varieties with varying maturity duration are required to escape frost (Canada) or late-season drought (southern Australia) or to fit in multiple cropping sequences (India, China). Breeding programmes are also concerned with a cultivar's suitability for existing or emerging management practices, e.g. herbicide resistance or mechanical harvesting (resistance to pod shattering).

Diversity in Global Production Systems

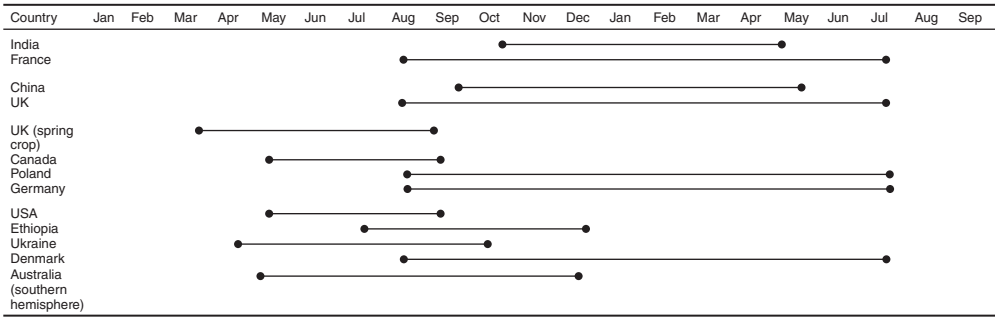
Oilseed brassica species are grown in around 50 different countries. This diversity of production is reflected in differences in species used, cultivar types, sowing and harvest times, length of growing seasons, oil quality types, yields, use of GM (genetically modified technology) and the major insect and disease challenges faced. *Brassica napus*, *B. rapa* and *B. juncea* have been widely used for oilseed production over many years. *Brassica carinata* (Ethiopian mustard) has predominantly been grown in Ethiopia. Attempts to convert *B. carinata* to a canola quality type have not been successful, but it is finding a niche as industrial products such as biodiesel. Depending on location, typical spring cultivars with no vernalization requirement require a growing season from around 120 to 190 days. This contrasts to over 300 days for European winter lines with a strong vernalization requirement (Table 1.1).

There are both regional and country differences in the relative use of open-pollinated cultivars compared with hybrids. In general, the increased involvement of private companies in canola breeding has led to an increased focus on the use of hybrids. In addition, the canola industry has also seen the introduction of GM cultivars.

Some major diseases and insects are common across different countries. This includes diseases such as blackleg (*Leptosphaeria maculans* (anamorph *Phoma lingam*)), Sclerotinia stem rot (*Sclerotinia sclerotiorum*) and Alternaria blight (*Alternaria* spp.) and insects such as aphids. Other diseases may be more localized. The same disease can be a major challenge to production in one area but of little consequence in another. Some pathogens are a significant problem across several *Brassica* species, while others are more of a major problem in one specific *Brassica* species but cause little or no damage on another species. White rust (*Albugo candida*) is one such species. While some insects are widespread across wide regions and even different countries, many insect problems can be more localized. For example, red-legged earth mite is a widespread and significant establishment pest in Australia but it is not an issue elsewhere. The relative importance of different diseases and insects can change dramatically with changes in race structures or environmental conditions. Changes in tillage practices (e.g. the introduction of minimum tillage) can also influence the severity of different insects and diseases. Several establishment pests have become a bigger problem with the introduction of minimum tillage practices such as stubble retention. The priorities of oilseed brassica breeders do not remain static, but need to be regularly adjusted to meet the challenges brought on by disease and insect variability, changing environmental conditions and other external pressures.

Status of oilseed brassica production in various countries is presented in Table 1.2. The table highlights the similarities and differences between countries in variety types, growing season, area of production, yield and pests. In the case of India, rapeseed-mustard crops are grown in diverse agroclimatic conditions ranging from north-eastern/north-western hills to down south under irrigated/rainfed, timely/late sown, saline soils and mixed cropping. *Brassica rapa* var. Brown Sarson, which once dominated the entire rapeseed-mustard growing region, has now been largely replaced by Indian mustard. Indian mustard accounts for about 75–80% of the 6.6 Mha under rapeseed-mustard in the country during 2013/14, contributing about 40% to the country's total edible oil supplies. Rajasthan, Haryana, Madhya Pradesh and Uttar Pradesh are the major rapeseed-mustard growing states with 47.2%, 12.6%, 11.0% and 10.3% contribution, respectively, to the national hectarage. The rapeseed-mustard production trends represent a fluctuating scenario with an all-time high production of 8.3 (Mt) from

Table 1.1. Sowing and harvest details for *Brassica* oilseed crops around the world.



6.9 (Mha) during 2010/11. The yield levels also have been variable, ranging from 854 (2002/03) to 1250 kg/ha (2013/14). Fluctuating and low productivity levels in India are a reflection of the low number of crop growing days, shorter day-length conditions during the bulk of growing season, stressed ecologies of cultivation and low productivity levels.

Taxonomy

Crop brassicas are the economically most important members of family *Brassicaceae* and the sub-tribe *Brassicinae*. A number of taxonomic treatises of the family *Brassicaceae* are available. These include Linnaeus (1753), De Candolle (1821), Baillon (1871), Prantl (1891), Schulz (1919, 1936) and Beilstein *et al*. (2006). Schulz's has so far been most comprehensive and authoritative description. A molecular account of the family has been recently provided by Beilstein *et al*. (2006). *Brassiceae* is among 19 tribes recognized by Schulz in the family *Brassicaceae* and is further subdivided into seven to nine sub-tribes (Gómez-Campo, 1980, 1999). *Brassica* is the major genus in this sub-tribe. Several members of related sub-tribes, such as *Raphaninae* and *Moricandiinae*, also show strong affinity with *Brassica*. This is despite the demonstrated distinctness of these species on the basis of chloroplast-DNA (cp-DNA) and restriction sites (Warwick and Black, 1991; Pradhan *et al*., 1992; Warwick *et al*., 1992). Cytogenetic investigations (Prakash and Hinata, 1980) have demonstrated that the three digenomic species, *B. carinata* (2n=34: BBCC), *B. juncea* (2n=36; AABB) and *B. napus* (2n=38: AACC), have originated through crosses between any two of the three elementary species *B. nigra* (2n=16; BB), *B. oleracea* (2n=18; CC) and *B. rapa* (2n=20; AA) (Fig. 1.1).

It is also now known that *B. nigra*, *B. rapa* and *B. oleracea*/*B. rapa* are the cytoplasm donor species for *B. carinata*, *B. juncea* and *B. napus*, respectively (Banga *et al*., 1983; Erickson *et al*., 1983). However, there are now indications that both *B. oleracea* and *B. nigra* might have also been cytoplasm donors for *B. napus* and *B. juncea*, respectively, in independent hybridization events during evolution of these species (Banga, personal communication). Major taxonomic forms are presented in Table 1.3.

Crop History and Ecology

Brassicas were among the earliest crops brought under domestication. Both *B. rapa* and *B. juncea* find mention in ancient Sanskrit literature dating back to 1500 BCE. These are also indicated in Greek, Roman and Chinese writings of 500 to 200 BCE (Downey and Röbbelen, 1989). The Chinese language equivalent of rapeseed was first recorded ca. 2500 years ago, and the oldest archaeological finds may date back as far as ca. 5000 BCE (Yan, 1990). In India, seeds of *B. juncea* found in archaeological sites have been dated to 2300 BCE (Parkash and Hinata, 1980). In Europe, domestication is believed to have occurred in the early middle ages and commercial plantings of rapeseed were carried out in the Netherlands during the 16th century.

Table 1.2. Summary of *Brassica* crop production in various countries.

Character	Australia	Canada	USA	China	India	France	Poland	Germany	UK	Ethiopia	Ukraine	Denmark
Sowing time	May–June (Autumn)	May	May (spring types) September (winter types)	September–October (Autumn)	September–November (winter)	August–September	August–September	August–early September	August–September	July	April–May (spring crop)	August–September (winter crop) March/April (spring crop)
Harvest time	November–December (Summer)	August–September	August–September (spring types) Late June–July (winter types)	May (Summer)	February–May	July	July	July	July	December	September–October (spring crop)	July (winter crop)
Length of growing season	150–190 days (spring varieties)	95–125 days	110–125 days (spring types) 270–300 (winter types)	210–230 days (semi-winter varieties)	130–150 days Some very early lines (110 days)	330 days	330 days	330 days	330 days Some spring sowing (180 days)	180 days	150–180 days Some winter sowing	330 days (winter crop)
Species used	Mainly *B. napus* Small amount of *B. juncea* *B. rapa* was also grown in the 1980s, but was discontinued	Mainly *B. napus* Limited *B. rapa* (decreasing) Limited *B. juncea* Some *B. carinata* (biodiesel production)	*B. napus* *B. rapa*	Mostly *B. napus* Small amount of *B. juncea*	*B. juncea* *B. rapa* Limited areas of *B. napus* *B. carinata*	*B. napus*	*B. napus*	*B. napus*	*B. napus*	*B. carinata*	*B. napus*	*B. napus*

Oil quality	Canola quality High oleic, low linolenic acid (HOLL)	Canola quality High oleic, low linolenic acid (HOLL) quality	Mainly canola quality Limited high erucic acid	Canola quality	Mainly high glucosinolates and high erucic acid Some canola-quality *B. napus*	Mainly canola quality Limited high erucic acid rapeseed (HEAR) production	Canola quality	Mainly canola quality Limited high erucic acid rapeseed (HEAR) production	Canola quality Limited high erucic acid rapeseed (HEAR) and high oleic, low linolenic acid (HOLL) production	High glucosinolates and erucic acid	Canola quality	Canola quality
Variety types	Hybrids Open-pollinated types	Mainly hybrids	Hybrids (spring) Open-pollinated types (winter)	Hybrids Open-pollinated types	Mainly open-pollinated types Some hybrids have been developed	Mainly hybrids	Hybrids and open-pollinated types	Predominantly hybrids	Hybrids and open-pollinated types Emphasis on hybrids	Open-pollinated types	Hybrids (winter) Open-pollinated types (spring)	Hybrids, Open-pollinated types
Major diseases	Blackleg Sclerotinia	Blackleg Sclerotinia Brown girdling root rot in (*B. juncea*)	Blackleg Sclerotinia	Sclerotinia Pre-emptive breeding against blackleg White rust (in *B. juncea*)	Sclerotinia Alternaria White rust (in *B. juncea*)	Blackleg Sclerotinia Alternaria Rhizoctonia	Blackleg	Blackleg Sclerotinia White leaf spot Alternaria	Blackleg Light leaf spot Sclerotinia Alternaria	Alternaria		Light leaf spot Sclerotinia Blackleg Alternaria
Major insect problems	Red-legged earth mite Diamondback moth	Flea beetles Bertha armyworm Aphids Diamondback moth	Aphids Harlequin bugs Diamondback moths Southern cabbage worm	Aphids	Aphids	Bertha armyworm Harlequin bug Flea beetle Lygus bug		Bertha armyworm Harlequin bug Flea beetle Lygus bug	Flea beetles Cabbage stem beetles Aphids Pollen beetles Seed weevils	Flea beetle		Flea beetles Pollen beetles

Continued

Table 1.2. Continued.

Character	Australia	Canada	USA	China	India	France	Poland	Germany	UK	Ethiopia	Ukraine	Denmark
Average yield (t/ha)	1.57	1.87	1.72	1.78	0.91	3.34	2.68	3.65	3.43	0.88	1.70	3.54
Average area (Mha)	1,359	6,712	441	6,770	6,582	1,508	798	1,436	639	>40	1,029	166
Average production (Mt)	2,127	12,568	759	12,055	5,990	5,040	2,140	5,248	2,192	>35	1,746	588

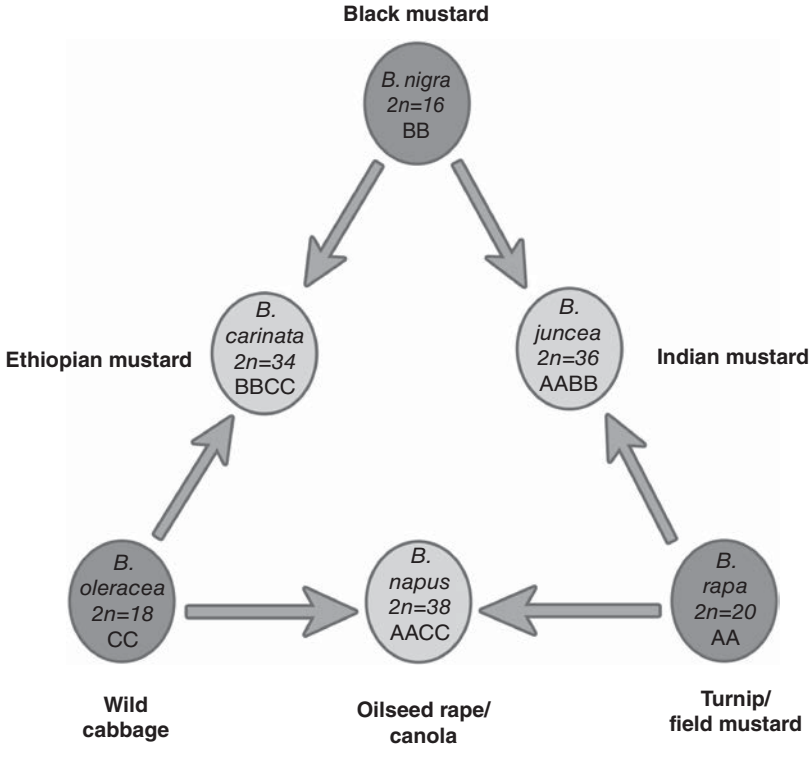


Fig. 1.1. U's triangle showing species relationships among different Brassica species (U, 1935).

At that time, rapeseed oil was used primarily as oil for lamps. Later, it became used as a lubricant for steam engines. Historically, *B. rapa* appears to have the widest distribution among brassica oilseeds. At least 2000 years ago it was distributed from northern Europe to China and Korea, with the primary centre of diversity in the Himalayan region (Hedge, 1976).

Brassica rapa

Wild *B. rapa* subsp. *oleifera* (inc. var. *sylvestris*) is arguably the originator species of var. *rapa* L. (cultivated turnip) and var. *sylvestris* (Lam.) Briggs (turnip-rape). 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 following domestication. Prakash and Hinata (1980) believed that oleiferous *B. rapa* developed in two places, giving rise to two different races, one European and the other Asian. Recent evidence (through analyses of chloroplast and mitochondrial DNA) suggests that *Brassica montana* (n=9) might be closely related to the prototype that gave rise to both cytoplasms of *B. rapa* and *B. oleracea* (Song and Osborn, 1992). Large morphological variation observed in *B. rapa* might have resulted due to the long history of breeding for different traits along with natural selection for adaptation in different geographical regions. Oleiferous and turnip forms developed in Europe, while in eastern Asia and West Asia these evolved into leafy and oleiferous forms. Various types of leafy vegetables of *B. rapa*, such as Chinese cabbage (*B. rapa* subsp. *pekinensis*), non-heading pakchoi (*B. rapa* subsp. *chinensis*) and mizuna, are found widely in

Table 1.3. Taxonomy of crop *Brassica* species.

Botanical name	Common name	Usage
B. nigra	Black mustard	Condiment (seed)
B. oleracea		Vegetable fodder (leaves)
var. *acephala*	Kale	Vegetable (head)
var. *capitata*	Cabbage	Vegetable (terminal buds)
var. *sabauda*	Savoy cabbage	Vegetable (head)
var. *gemmifera*	Brussels sprouts	Vegetable, fodder (stem)
var. *botrytis*	Cauliflower	Vegetable (inflorescence)
var. *gongylodes*	Kohlrabi	Vegetable, fodder (stem)
var. *italica*	Broccoli	Vegetable (inflorescence)
var. *fruticosa*	Branching bush kale	Fodder (leaves)
var. *alboglabra*	Chinese kale	Vegetable (stem, leaves)
B. rapa		
subsp. *oleifera*	Turnip rape	Oilseed
var. Brown Sarson	Brown sarson	Oilseed
var. Yellow Sarson	Yellow sarson	Oilseed
var. Toria	Toria	Oilseed
subsp. *rapifera*	Turnip	Fodder, vegetable (root)
subsp. *chinensis*	Bok choi	Vegetable (leaves)
subsp. *pekinensis*	Chinese cabbage	Vegetable, fodder (head)
subsp. *nipposinica*	–	Vegetable (leaves)
subsp. *pamchinensis*	–	Vegetable (leaves)
B. carinata	Ethiopian mustard	Vegetable oilseed
B. juncea	Mustard	Oilseed, vegetable
B. napus		
subsp. *oleifera*	Rapeseed	Oilseed
subsp. *rapifera*	Rutabaga, swede	Fodder

East Asia, particularly in China, Korea and Japan. The oleiferous form of *B. rapa* (*B. rapa* subsp. *oleifera*) has been historically cultivated for production of vegetable oils in China, Canada, India and in northern Europe and is the third brassica oilseed crop. The Indian form developed into a mainly oleiferous form such as the *B. rapa* vars Yellow Sarson, Brown Sarson and Toria that are grown over large areas in eastern and north-eastern parts of India during the winter season (Singh, 1958).

Brassica oleracea

This crop was domesticated as early as 2000 BCE initially as primitive kales or cabbages. These are now believed to be the first cultivated forms of *B. oleracea* (Chiang *et al*., 1993), especially by Celts whose name 'Bresic' for cabbage may be the likely progenitor of '*Brassica*'. Heading cabbages and other leafy types probably had a common origin from the ancestral kales and non-heading cabbages (Herve, 2003), and they were further developed in Portugal, Spain and France. Wild forms of *B. oleracea* are found on the Atlantic coasts of Europe, northern France and England. Related wild species are endemic to the Mediterranean basin. Because the cultivated *B. oleracea* crops were grown in close proximity to wild relatives, the flow of genes from wild to cultivated types probably occurred. This coupled with mutation, human selection and adaptation must have contributed to current morphogenetic variation in this crop.

Brassica nigra

Brassica nigra or black mustard was originally domesticated in Asia Minor or Iran, and has been cultivated since ancient times. It was the primary condiment mustard all over Europe

but subsequently gave way to brown mustard or *B. juncea*. It is native to the Mediterranean region, and archaeological finds show that it has occurred as a weed in association with the cultivation of wheat and barley during domestication. Historically, black mustard appeared to have been harvested mainly from wild populations with only sporadic commercial cultivation.

Brassica carinata

This is an amphiploid derived from natural hybridization between *B. oleracea* and *B. nigra* in Ethiopian highlands. Despite significant efforts, it has not been possible to locate any wild forms (Mizushima and Tsunoda, 1967). However, both the species are commonly observed growing close to each other in cultivation or as escapes. This crop has been domesticated for multiple uses such as oil, condiments, medicines and vegetables (Astley, 1982; Riley and Belayneh, 1982).

Brassica juncea

This is a natural amphiploid derived from crosses between *B. rapa* and *B. nigra*. The origins of *B. juncea* are unclear, but it must have originated in areas like the Middle East and neighbouring regions, where distributions of *B. nigra* and *B. rapa* overlap (Prakash and Hinata, 1980). The concept of a separate origin of foliage types (Chinese) and oleiferous types (Indian) was mainly based upon the investigations of Vaughan *et al*. (1963) and Vaughan (1977) on seed glucosinolate profiles. Vaughan (1977) also suggested that the Indian race was closer to the *B. rapa* progenitor, and the oriental race was closer to the *B. nigra* progenitor, and perhaps this indicates that *B. juncea* evolved into more than one region. Spect and Diederichsen (2001) considered the place of origin somewhere between Eastern Europe and China, where there is parental sympatry. *Brassica juncea* has been divided into four subspecies, with different morphology, quality characteristics and uses (Spect and Diederichsen, 2001). These are: (i) subsp. *integrifolia*, used as a leaf vegetable in Asia; (ii) subsp. *juncea*, cultivated mainly for its seed, occasionally as fodder; (iii) subsp. *napiformis*, used as a root-tuber vegetable; and (iv) subsp. *taisai*, stalks and leafs of which are used as vegetables in China.

Brassica napus

Brassica napus is thought to have multiple origins resulting from independent natural hybridization events between *B. oleracea* and *B. rapa*. In Europe, the winter form has predominantly become a common yellow crucifer of wild areas. In the British Isles, for example, it has been naturalized wherever oilseed rape is grown, and it is a relatively recent introduction into Canada, the USA, China and India.

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