Rapeseed genetics and breeding research for sustainable oilseed production

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Abstract

Rapeseed (canola) is among the world's most important oilseed crops. The development and commercial utilization of zero erucic acid, low glucosinolate cultivars, referred to as "double low" cultivars or canola in Canada, was the basis for increased production of rapeseed as a high quality edible oil and a high quality protein supplement in animal feed. These improvements in crop quality were achieved through plant breeding efforts which identified the desired phenotypes and incorporated these traits into adapted, elite germplasm and cultivars of spring and winter oilseed rape, *Brassica napus* L. The whole Canadian, Australian and European oilseed rape acreage is now of "double low" quality. Canola quality cultivars have also been developed in *B. rapa* and recently in *B. juncea*; *Brassica* oilseed species of significant economic importance in China and India, as well as Canada. Significant increases in seed yield have been achieved in *B. napus* through the development of hybrid cultivars, and the contribution of hybrid cultivars to improved productivity and sustainable production will be reviewed. Basic genetic studies on seed, oil and meal quality attributes of rapeseed laid the foundation for the development and implementation of efficient and effective breeding strategies for the breeding of high quality oilseed rape cultivars and hybrids, and this research will be reviewed. The development of disease resistance was and is a major factor to reduce production risks in rapeseed for a more sustainable production. Significant progress was made in this area in recent years. The research included intra- as well as interspecific crossing and selection strategies to develop the desired quality and disease resistant types in the different *Brassica* oilseed species. The development of herbicide tolerant transgenic *B. napus* cultivars and hybrids in Canada will also be reviewed.

Key words: Rapeseed, canola, sustainable production

Introduction

Rapeseed (canola) is among the world's most important oilseed crops. The eight major producing countries are Australia, Canada, China, France, Germany, India, Poland and the UK. These countries account for 98% of total world rapeseed production.

Table 1: World rapeseed production (in 1000 tonnes) in countries with >100,000 tonnes annual production, 2003 (FAO Statistical Yearbook 2004).

Countries	1000 tonnes	Countries	1000 tonnes
Australia	1,622	India	3,842
Bangladesh	218	Lithuania	120
Canada	6,669	Pakistan	250
China	11,410	Poland	754
Czech Republic	388	Russian Federation	192
Denmark	280	Sweden	130
France	3,341	UK	1,771
Germany	3,638	USA	686
Hungary	104	World	36,146

China produced 11,410,000 tonnes of rapeseed in 2003 (32% of total world production) and was the world's largest producer, followed by Canada (6,669,000 tonnes) and India (3,842,000 tonnes). The three European countries France, Germany and the UK produced a total of 8,750,000 tonnes more than Canada. There also is significant rapeseed production in Australia (1,622,000 tonnes). The total world rapeseed production in 2003 was 36,146,000 tonnes.

The European countries grow the winter annual form of *Brassica napus* and achieve seed yields of about 3,000 kg/ha (France, Germany, UK) while in Canada the summer annual form of *B. napus* is grown in the western prairie provinces with average seed yields of about 1,000 to 1,500 kg/ha. Summer as well as semi-winter types of *B. napus* are grown in China with seed yields similar to those in Canada. Seed yields in India are less than 1,000 kg/ha, and production is based on *B. rapa* and *B. juncea* species cultivars.

Materials and Methods

Currently the most widely grown and most productive species is *Brassica napus*, grown as a high yielding winter annual crop in western Europe with seed yields of greater than 3 to/ha. Canada and Australia utilize summer annual forms of *B. napus* and China grows both, summer and winter annual forms. India grows primarily *B. juncea* Indian mustard as an oilseed crop. There are large semi-arid growing regions in the world that cannot successfully cultivate *B. napus* which is a cool season crop. The mustard species *B. juncea* has much better heat and drought tolerances than *B. napus*, and also has much better pod (seed) shatter tolerance than *B. napus*. Canola-quality *B. juncea* cultivars should be developed to expand rapeseed production into the dry areas of the world and thereby increase rapeseed production (Potts et al. 1999). Countries such as China (north-western China), India, Australia and parts of western-Canada would then be able to significantly increase their productions. *Brassica carinata* is another potential species for production in dry areas, and is viewed by some researchers as the most heat and drought tolerant and best blackleg resistant of the three amphidiploid *Brassica* oilseed species. Again, the development of canola-quality lines is a prerequisite for its utilization as an oilseed crop. *Brassica rapa* which has been grown in Canada on significant acreages in the past and is still grown in parts of China and India, as well as in Scandinavian countries will be of importance for very short season growing areas. We have conducted research in *Sinapis alba* yellow mustard and developed canola-quality material as a starting point towards an oilseed *S. alba* crop for dry areas (Katepa-Mupondwa et al. 1999).

Blackleg disease caused by the fungus *Leptosphaeria maculus* is the most important disease in *Brassica* oilseed crops and in particular for *B. napus* (Brun et al. 2003, Relf-Eckstein et al. 2003). Genes for resistance to blackleg have been identified and are being incorporated into new cultivars (Delourme et al. 2003). There are minimum requirements for levels of blackleg resistance for registration of new cultivars. Resistance breeding is the most cost effective method for the protection of rapeseed from blackleg disease. Pathologists distinguish between qualitative seedling resistance and quantitative adult plant resistance. *Brassica juncea* has good levels of blackleg resistance and levels in *B. carinata* seem to be even greater which will make these two species a valuable addition to the canola (double low) "rapeseed" species portfolio.

Stem rot disease caused by *Sclerotinia sclerotiorum* is a major threat to rapeseed production in all *Brassica* species. Resistance breeding is difficult and fungicidal control of the disease is complicated since predictions for the possible occurrence of infections are not always reliable. Chinese researchers have made significant progress in developing stem rot resistant *B. napus* cultivars (Liu 2003). One quarter of the total Chinese rapeseed acreage was planted to the resistant cultivar Zhongyou 821 during the 10 year period 1988-1998 and stem rot resistant canola-quality material is now also available (Wang et al. 2003).

White rust disease is caused by *Albugo candida*. This disease is not found in *B. napus*, all cultivars are highly resistant to this disease. However, *B. rapa* and *B. juncea* are highly susceptible and the use of *B. rapa* and also *B. juncea* parents in crosses with *B. napus* has resulted in white rust susceptible *B. napus* in China. The disease is severe in *B. juncea* in India and resistant germplasm is desperately needed (Yadav & Kumar 2003).

The development of hybrid cultivars is an important method for increasing and stabilizing seed yields. In Canada and Europe, hybrid cultivar breeding in *B. napus* is conducted by private companies. The genetic diversity for hybrid breeding in *B. napus* is limited and new genetic diversity must be created to make hybrid development profitable (Quijada et al. 2004, Udall et al. 2004, Qian et al. 2006). Hybrid cultivars could also be developed in *B. rapa*, *B. juncea* and *B. carinata* in the future. The genetic diversity in *B. rapa* and *B. juncea* germplasm is much greater than in *B. napus*, and therefore prospects for the development of superior hybrid cultivars in these species is excellent. We still need to research hybrid seed production systems to improve the economics of production of hybrid seed, and to guarantee high levels of hybridity in commercial hybrid seed for reliable hybrid performance.

The genetic improvement of oil and meal quality of *Brassica* oilseeds will be important an aspect to increase sustainable production. The methods for increasing oil and protein contents are well established. The creation of low fibre (yellow-seeded) *B. napus* was accomplished through interspecific crosses (Rashid et al. 1994, Rahman 2001) and the next task is to improve agronomic performance, disease resistance and seed quality (oil and protein contents) of low-fibre yellow-seeded lines and to develop hybrid cultivars. Development of high stability specialty oils with high oleic and low linolenic acid contents in *B. napus* was accomplished through seed mutation (Rakow 1973) as was the development of low saturated fat *B. napus* (Raney et al. 2003).

The development of transgenic herbicide tolerant *B. napus* canola has been pioneered in Canada where 85% of the total acreage was planted to herbicide tolerant cultivars in 2002 (Downey & Buth 2003), and the acreage planted to GM canola has further increased in recent years, in particular the acreage sown to Liberty Link herbicide tolerant hybrid cultivars because of their superior agronomic performance. The contribution of GM breeding technology has had a major impact on the sustainability of canola production in Canada. This technology is not available to producers in other countries, except the USA, due to government legislation and regulations.

Results

Brassica juncea canola was successfully developed in Canada in a collaborative research project between the Saskatchewan Wheat Pool and AAFC Saskatoon Research Centre.

The *B. juncea* lines J90-4316 and PC97-32 are of the zero erucic acid, low glucosinolate (non-allyl glucosinolate) type. Low oleic acid content in wild type zero erucic acid *B. juncea* of about 45% is not acceptable by the canola industry in Canada, the line PC97-32 has an oleic acid content comparable to that of *B. napus* canola of 65%. The blackleg resistance of *B. juncea* canola is excellent. The Saskatchewan Wheat Pool has developed several cultivars (Arid, Amulet, Dahinda, Estlin) that are currently marketed under contract production.

Table 1. Performance of *Brassica juncea* canola at 17 locations in western Canada, 1997 and 1998. (Source: D. Potts, et al. 1999).

Entry	Yield(% checks)	Mat.(days)	Oil(%)	Protein(%)	Oleic-acid(%)
B. napus	103.4	85.6	46.0	45.1	63.6
B. rapa	96.6	75.8	46.4	42.5	59.7
J90-4316	120.4	84.6	43.2	42.6	45.4
PC97-32	109.9	86.5	44.6	45.2	65.2

B. napus: AC Excel, Defender, Legacy
B. rapa: AC Parkland, Maverick, Reward

There have been many successes in developing disease resistant cultivars continued breeding work will produce the needed resistances. Hybrid cultivar breeding was initiated in the early 1980s and hybrid cultivars have captured a significant portion of the canola acreage in many countries. There have been major improvements in canola oil and meal quality, and genetic and breeding research was the key in the development of the rapeseed crop. The next goal will be the creation of low fibre meal (yellow-seeded) cultivars.

Discussion

Species diversification will contribute significantly to increased sustainable rapeseed (canola) production in the future. Examples will include drought and heat tolerant *B. juncea* canola cultivars that are highly resistant to blackleg disease and shatter tolerant. It will genetically be more efficient and easier to modify the seed quality characteristics of an adapted species such as *B. juncea* rather than try to adapt *B. napus* to dry growing conditions. Similarly, for very short season growing areas, the early maturing *B. rapa* species is the species of choice. It needs to be seen where *B. carinata* and *S. alba* have a place as oilseed species in the world. Our breeding efforts have to focus on species diversification to reduce the dangers associated with world wide monoculture of *B. napus* to minimize disease risks and to realize the production potential inherent in the other species for a sustainable *Brassica* oilseed production.

Hybrid cultivar development must be a goal in all species to stabilize and increase seed yields, hybrid cultivars will also handle stress conditions (biotic and abiotic) better than open pollinated cultivars. Quality breeding will continue to play an important role in improving the competitiveness of oilseed *brassica*s compared to other oilseeds. We will have to pay special attention to meal quality improvements to ensure its future use as a high quality protein supplement in animal feed relative to soybean meal with the expected increase in the rapeseed acreage due to growing demands of rapeseed oil as a biofuel (biodiesel).

Conclusions

Genetic studies and breeding of improved high quality *Brassica* oilseed cultivars and hybrids will make the greatest contribution to sustainable rapeseed production in the future. It will be important that we continue to provide the needed financial and human resources to rapeseed breeding research and cultivar breeding so that these goals can be achieved.

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