Status of *Brassica* research and production in Spain

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Introduction

Currently, rapeseed (*Brassica napus*) is a minor oilseed crop in Spain with only 6000 Has in 2003 compared to a cultivated area of 700.000 Has for sunflower. Rapeseed was introduced in Spain at the end of the seventies. It showed good performance perspectives, in comparison to sunflower and other oilseed crops, due to its better adaptation to the rain distribution of most of the Spanish climatic conditions, since it can be cultivated as a winter crop. However, this introduction suffered an important handicap in 1981 due to problems derived from the fraudulent use of industrial rapeseed oil for adulteration of edible oil, which caused serious health problems. The interest for cultivation of rapeseed started again in 1984 and from this year to 1993 the cultivated area averaged 10.600 Has with a total production of 14,700 metric tons (Table 1).

Table 1. Rapeseed production and yield in Spain from 1985 to 2003

Year	Area (1000 Has)	Production (1000 Mt)	Yield (Kg/ha)
1984-1993			
Mean	10.6	14.7	1424
Range	4.9-24.1	9.5-29.7	1168-1939
1994-1998			
Mean	73.5	77.1	1104
Range	46.5-97.6	55.7-108.0	583-1562
1999	48.3	57.2	1184
2000	31.4	49.6	1579
2001	24.6	35.9	1459
2002	6.4	10.2	1593
2003	6.0	11.3	1883

The production increased substantially in the period 1994-98, with an average of 73.000 Has and a production of 108.000 metric tons of seed although these figures were far from those of sunflower with about one million of Has dedicated to this crop in this period. In recent years, the area dedicated to rapeseed has declined drastically down to about 6000 has in 2002 and 2003.

In spite of the agronomic advantages of rapeseed and other *Brassica* oil crops for most of the rainfed conditions of Spain, the competition with sunflower caused that they never became major crops. One of the main reason for that is that sunflower is a very easy crop to cultivate under Spanish conditions, with lower cultivation costs than rapeseed, lower incidence of pests and diseases, and absence of some problems of cultivation present in this crop, specially shattering under dry and high temperature conditions. Another reasons are the better prices of sunflower seed paid to the farmers and the interest of the industry for sunflower oil, which has a high demand by the consumers.

Some factors may change this situation in the next years: One is the increasing incidence of very virulent races of broomrape, a parasitic plant that may limit the cultivation of sunflower in some areas and make necessary the introduction other crops in the rotation. With this situation, the production of *Brassica* crops, especially *B. carinata*, with a high availability of oil types suitable for edible and industrial uses, excellent adaptation to the Mediterranean conditions and more resistance to pod shattering and diseases than rapeseed, may increase substantially. This increase will be favoured by EU policy in relation to energy crops for the production of biodiesel.

Research

Early research work in Spain, conducted by public and private institutions, was mostly focused on developing rapeseed material adapted to different Spanish climatic conditions. Private research, carried out by seed companies, has released some cultivars selected under Spanish conditions, but a high proportion of the cultivars inscribed have been selected in other European countries. Most of the public research on oil crops is carried out by the Institute for Sustainable Agriculture (IAS) at Córdoba, belonging to the Spanish Council of Scientific Research (CSIC), and by the Center of Agrarian Research of Córdoba (CIFA), belonging to the Regional Government of Andalusia. Better yielding low erucic-acid cultivars were crossed with double-low material and several double low cultivars were released.

Evaluation of selected material from introductions of *B. napus,* Indian mustard (*B. juncea*) and Ethiopian mustard (*B. carinata*) demonstrated that the latter species had better performance than *B. napus*, especially under high water deficit conditions, as well as other agronomic advantages such as resistance to pod shattering and to a wide range of diseases and pests (Fereres et al., 1983). However, all the natural occurring Ethiopian mustard forms had high erucic acid and high glucosinolate content in the seeds. Therefore, taking into account the potential of this species as an oilseed in Spain, breeding programs were initiated in 1986 by both private and public institutions in order to improve the quality of the seed oil and meal in Ethiopian mustard.

Breeding efforts resulted in the development of zero erucic acid genotypes obtained from cross breeding and continuous pedigree selection (Alonso et al., 1991) or interspecific breeding with *B. napus* and *B. juncea* (Fernández-Escobar et al., 1988; Fernández-Martínez et al., 2001) as well as the development of low, medium and very high erucic acid content mutants using mutagenesis (Velasco et al., 1995, 1998). Genetic studies showed, similarly to other amphidiploids *Brassica* species, that two loci E_1 and E2 acting in an additive manner were involved in the control of erucic acid in *B. carinata* (Del Rio et al., 2003). With this model, the zero erucic line was hypothesized to have the genotype $e_1e_1e_2e_2$.

In contrast to zero erucic acid *B. napus*, the process of elimination of erucic acid in *B. carinata* was associated to a considerable increase of the concentration of linolenic acid (> 20 %) and a relatively low concentration of oleic acid. Thus, the oil profile of the zero erucic acid Ethiopian mustard consisted of 33% oleic, 37% linoleic and 21% linolenic (Alonso et al., 1991; Fernández-Martínez et al., 2001) compared to 61% oleic, 21% linoleic and 11% linolenic acid in canola oil (Scarth and McVetty, 1999). Because of the detrimental effect on oil stability of polyunsaturated fatty acids, their substitution for the monounsaturated oleic acid was considered to be an important goal for the development of higher quality mustard oil. Therefore, further breeding efforts were made to increase the levels of oleic and reducing linolenic acid levels in zero erucic acid Ethiopian mustard. Several mutants with increased oleic acid (20% compared to 10% in the control) and a mutant with reduced linolenic acid (5% compared to 12% in the control) were obtained by mutagenesis in a high erucic acid line (Velasco et al. 1997a). Another source with similar reduced levels of linolenic acid was developed through selection from a germplasm accession of this species (Velasco et al. 1997b).

Genetic studies on these materials revealed that the increased oleic-acid concentration was controlled by alleles at one locus (Velasco et al., 2003a) while three different loci (Ln, Ln1 and Ln2) were found to be involved in the control of reduced linolenic acid (Velasco et al., 2003b). A second locus Ol2 for increased oleic concentration was identified in a transgressive segregation from a cross between lines with increased oleic and reduced linolenic acid. Transgressive segregants with high oleic acid transferred to a zero erucic background resulted in a zero erucic acid germplasm with very high oleic acid concentration (83.9% compared to 32.95% in the standard zero erucic line) and a low linolenic acid concentration (5% compared to 16% of the standard line). This line was hypothesized to have the genotype *ololol2ol2LnLnln1ln1ln2ln2* and the two genes *e1e1e2e2* for zero erucic acid (Velasco et al 2003b). It is expected a subsequent increase of oleic acid concentration by introgressing *ln* alleles for reduced linolenic acid content. Additionally, other two lines exhibiting mid oleic acid (70.7% and 79.5% respectively), and lines with high linoleic acid (60.6%) and high linolenic acid (34.5%) have also been identified (Nabloussi et al., 2003). The research on oil quality has made available in Ethiopian mustard zero erucic germplasm with very different oil types, some similar to mid oleic canola types but others with very high oleic, high linoleic and high linolenic as well as very high erucic. This diversity of fatty acid profiles has a big potential for industrial and nutritional applications.

The other factor limiting large-scale cultivation of Ethiopian mustard either for edible or industrial oil production, is the presence of high levels of glucosinolates in the seeds. Breeding efforts carried out at Córdoba to develop low glucosinolate *B. carinata* have followed several approaches. A first approach was to carry out a pedigree selection for low glucosinolate content in lines with good agronomic performance. After several generations a line with an average glucosinolate content of 82 μmoles g^{-1} seed compared to 115 μmoles g^{-1} seed of the starting material (Velasco et al., 1999). Another strategy was the use of chemical mutagenesis. Five mutants with an average glucosinolate content between 20 and 30 μmoles g^{-1} seed lower that the parent (125 μmoles g^{-1} seed) were obtained (Velasco et al., 1999). Currently, our group is involved in the transfer of genes controlling low glucosinolate content from *B. napus* and *B. juncea.*

In the next future, further efforts are required in *B. carinata* to develop germplasm with lower glucosinolate content and to incorporate different fatty acid profiles, suitable for either edible or industrial purposes, into good performance genotypes. Another important aim of research in this species is to improve the winter-hardiness of present promising material.

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