Efficacy of imazamox in imidazolinone-resistant spring oilseed rape in Finland

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Imidazolinonies (IMIs) are a group of herbicides inhibiting acetolactate synthase (ALS) activity. They control the growth of many broadleaved weeds and annual grass species. Herbicide resistance against imidazolinonies has been transferred in some crop species, for example in *Brassica napus*. IMI-resistant oilseed rape cultivars have been developed by a mutation in ALS. They have been on the market for a few years, especially in North America. To determine if imazamox, an imidazolinone herbicide, and IMI-resistant oilseed rape cultivars are suitable for cultivation in Finland, we conducted four herbicide trials in three locations. We found, that imazamox had no negative effect on yield or oil quality characters of IMI-resistant oilseed rape. Some transient chlorosis was observed immediately after the treatment, but it was not apparent after a few days. The effects of imazamox against the most troublesome weeds in oilseed field in Finland, *Chenopodium album* and *Galium spurium*, were very good. Imazamox had good or moderate effects on *Stellaria media*, whereas its effects on *Viola arvensis, Lapsana communis* and *Fallopia convolvulus* were insufficient. If the total weed number was high or the emergence of oilseed rape was slow, the application of imazamox increased the yield of oilseed rape compared to untreated control. Our results suggest that imazamox is a good alternative in controlling weeds for Finnish oilseed fields. Therefore, it would be beneficial to transfer the IMI-resistance into Finnish oilseed and turnip rape lines.

Key words: acetolactate synthase, herbicide resistance, imidazolinone herbicides, oilseed rape, weeds

Introduction

Since the early 1970s spring turnip rape (*Brassica rapa* L.) and oilseed rape (*Brassica napus* L.) have established their important roles among annual field crops in Finland. In addition to the food and non-food use, they can break the one-sided crop cereal rotations; for this reason their value as a preceding crop in the crop rotation is high. In the last two decades the acreage of cultivated turnip and oilseed rape in Finland has been approximately 60,000 hectares (Ministry of Agriculture and Forestry 2003).

In order to produce good quality oil and meal, the oil milling industry has strict quality parameters for the raw material. One such parameter is a low content of weed seeds (under 3%), given that weed seeds both lower the quality of oil and make the processing difficult. Currently, development of new strategies for weed management in oilseed production is necessary, since one of the widely used predrilling herbicide, trifluraline, is planned to be taken off the market leaving only one alternative herbicide (Ministry of Agriculture and Forestry 2003). A potential solution for the problem is the incorporation of herbicide resistance into the genome of oilseed varieties (Mazur and Falco 1989, Burnside 1992).

Herbicide-resistant crops have been developed by conventional plant breeding for resistance to imidazolinones (IMIs), sethoxydin and triazines and through genetic engineering for resistance to bromoxynil, glyphosate, glufosinate, sulfonylureas and 2,4-D (Monaco et al. 2002). In oilseed rape, the most important forms of herbicide resistance are transgenic approaches, such as glyphosate resistance (Roundup Ready™) and glufosinate resistance (Liberty Link™), and imidazolinone resistance (IMI-resistance). In the latter case, the resistance trait has been introduced by classical breeding methods (Monaco et al. 2002).

IMI-resistance in oilseed rape was developed by exposing oilseed rape microspores to ethylnitrosourea resulting in mutation of the acetolactate synthase (ALS) (EC 4.1.3.18) gene (Swanson et al. 1989). The target enzyme for IMI herbicides is ALS or acetohydroxyacid synthase (Shaner et al. 1984, Stidham 1991, Vaughn and Duke 1991, Dekker and Duke 1995). The enzyme catalyzes the production of the branched chain amino acids: valine, leucine and isoleucine (Umbarger 1978, Shaner et al. 1984). The reactions, which ALS catalyzes, are: 1) 2 pyruvate $\rightarrow$ acetolactate + CO_2 and 2) pyruvate + α-ketobutyrate $\rightarrow$ acetohydroxybutyrate + CO_2 (Singh et al. 1988). The biosynthesis of branched chain amino acid occurs in chloroplasts (Monaco et al. 2002). When valine, leucine and isoleucine production is inhibited by imidazolinones, plant growth decreases and is followed by plant death (Shaner et al. 1984, Dekker and Duke 1995).

IMI resistant cultivars have been on the market for a few years, especially in North America (Clearfield™ and SMART™). In addition to oilseed rape, IMI-resistant cultivars have been developed in wheat, corn, rice, sugar beet, sunflower, sugarcane and soybean (Lovell et al. 1996, Monaco et al. 2002, Poston et al. 2002).

The imidazolinone herbicides were developed in the 1980s (Los 1987, Shaner 1991). Their mechanism of action is similar to sulfonylureas, the very commonly used herbicides in Finland. Both herbicide groups inhibit ALS (Chafleff and Mauvais 1984, Shaner et al. 1984). Chemically, these herbicides are different (Stidham 1991). The other ALS-inhibitors are triazolopyrimidine sulfonanilides and pyrimidinylthiobenzoates (Tranel and Wright 2002). In imidazolinones, the chemical group with an imidazolinone ring is bonded to an aromatic ring (Stidham 1991). There are several subcompounds in this group, such as imazaquin, imazethapyr and imazamox (Monaco et al. 2002). Due to their efficiency and favourable health and environmental characteristics, such as low mammalian toxicity and low application rates, imidazolinones are a popular group of herbicides (Mazur et al. 1987, Bernasconi et al. 1995).

Although imidazolinonies are not yet used in Finland, they should be considered as alternative herbicides for rapeseed. Therefore, their suitability for use in Finland should be tested. Some preliminary trials were made with IMI-resistant Canadian oilseed rape cultivars in 2001 in Tuusula, Finland.

On the basis of these trials, the Canadian cultivars were found to be late maturity types, but they were well suited for testing imidazolinonies on the Finnish weed flora. The objective of this study was to investigate the potential use of IMI-resistant rapeseed cultivars in Finland: the effect of imidazolinone on weeds, the phytotoxicity of imazamox on IMI-resistant Canadian cultivars and the proper application rates of imazamox.

Material and methods

Field experiments

The effect of imazamox on dicotyledon weeds and on oilseed rape tolerance was investigated in field trials during 2002 and 2003. In both years, the trials were conducted in two locations: 2002 at Anttila Experimental Farm, Tuusula (Exp 1) and at Jokioinen, MTT Agrifood Research Finland (Exp 2); and 2003 at Viikki Experimental Farm, University of Helsinki (Exp 3) and at Jokioinen (Exp 4). The variety used in these trials was IMI-resistant oilseed rape, Hylite 243 cl (Advanta). The exception was Exp 1, where IMI-resistant Hylite 215 cl (Advanta) was used. The experimental design was randomized complete block with three (Exp 1) or four (Exp 2-4) replicates. The herbicide used was imazamox (Raptor®, a.i. ammonium salt of 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid at 40g l^{-1}, BASF Corporation, USA). The application rates of imazamox were 30 g ai ha^{-1}, 40 g ai ha^{-1} and 60 g ai ha^{-1} with surfactant Super Biokiinnite at 0.25% (v/v) (Mildola Ltd., Finland) and 30 g ai ha^{-1} without surfactant. The control plot was left untreated. The plot sizes were from 10.96 to 25.2 m^2 (12.5 cm between rows). The trials were sown on 8 May 2002 (Exp 1 and 2) and on 23 (Exp 4) and 26 (Exp 3) May 2003. Imazamox was applied when oilseed rape was at 3 to 4-leaf stage (BBCH 13-14) (Hack et al. 1992). The application was made by using tractor-mounted sprayer in Tuusula and hand-held sprayer in Jokioinen and Viikki at 200 l ha^{-1}.

Field observations

During the growth season observations of growth (emerging and flowering date, plant height, days to end flowering, lodging and days to mature) were made in Exp 1 and 3. The phytotoxicity effect of imazamox on spring oilseed rape was observed visually three times after the treatment. In addition, the effect of the herbicide on dicotyledon weeds was observed visually two times after the treatment. Phytotoxicity assesments were made in all trials and effects on weeds were assessed in Exp 2 and 3.

Weed counting and dry weight measurements

The number of dicotyledon weeds per m^2 was counted and the dry weights determined 34–38 days after the herbicide treatment (DAT). An exception was Exp 1, where the counting of weeds was made 9 DAT. The number of weeds on a total area of 0.5m^2 (2 x 0.25m^2) in Exp 1 and 3 and 1.0 m^2 (2 x 0.5m^2) in Exp 2 and 4 was determined in each plot.

Yield and chemical analysis

After maturation, yield was combine-harvested. The growing times (time from sowing to harvesting) for Exp 1, 2, 3 and 4 were 113, 112, 114 and 111, respectively. After harvesting, seed yield (kg ha^{-1}), seed purity (%) and 1000 seed weight (g) were measured.

Oil-, protein-, chlorophyll- and fatty acid-analyses were carried out from Exp 1 and 3. For chemical analysis, samples were pooled between replicates. The aim of the chemical analysis was to verify that chemical composition remained unchanged. The oil content was measured by NMR (nuclear magnetic resonance spectrometry, Bruker NMS 110 minispec, Germany) and the protein and chlorophyll were measured by NIR (near infrared spectrometry, Perten DA 7000, Sweden). Both

analyses were made from whole seed samples. The fatty acids were analysed by gas chromatograph (HP 5890, USA). The preparation of fatty acid samples was done according to the protocol of ISO 5509/ISO 5508.

Statistical analyses

The experimental design in all the four field experiments was the randomized complete block design with three or four blocks in which the five treatments (four herbicides and untreated plot) were randomized to plots within each block separately. Variability in the measurements was unequal in the different experiments and therefore each experiment was analysed separately. Statistical analyses of the data were based on the following mixed model:

$$Y_{ij} = \mu + b_i + T_j + \varepsilon_{ij},$$

where Y_{ij} is the response for block i and treatment j; μ is the overall mean; b is the random block effect; T is the fixed effect of treatment; ε is the random error term. The random effects b_i and ε_{ij} are assumed to be mutually independent and normally distributed with zero means and variances σ_b^2 and σ_ε^2 respectively. The models were fitted with use of the residual maximum likelihood (REML) estimation method. The degrees of freedom were computed by a method described by Kenward and Roger (1997). Analyses were performed by the MIXED procedure of the SAS/STAT software (Littell et al. 1996). The residual analyses were carried out to check the assumptions of the models. The residuals were checked for normality using a box plot (Tukey 1977) and were also plotted against the fitted values. Comparisons of the treatments were made by two-sided t-type tests. Number and dry weight of the species *Chenopodium album*, *Viola arvensis* and *Lapsana communis*, total number of weeds and seed purity were non-normally distributed. To obtain normality logarithmic transformations were used for the number of *C. album*, *V. arvensis*, *L. communis* and total weeds, as well as for the dry weight of *V. arvensis*.

Instead, square root transformation was applied for the dry weight of *C. album* and for the total number of weeds and arcsine transformation for the seed purity. The growth time observations in Exp 1 and 3 were analysed separately by using Agrobase™- program (Mulitze 1991).

Results

Field observations

Imazamox treatments did not affect oilseed rape flowering time, height, maturation, or late-season lodging (data not shown). The only statistically significant difference was observed in percentage of lodging at the end of flowering in Exp 1. These differencies were not, however, a result of imazamox treatment since there were no correlations between treatments and the rate of lodging. Chlorosis was observed in oilseed rape 1 to 3 DAT, especially in the treatments (30, 40 and 60 g ai ha^{-1}) with surfactant (Table 1). If the first phytotoxicity observation was delayed to 7 DAT (Exp 3), no symptoms were observed.

Visual observations of the effect of imazamox on dicotyledon weeds were observed in Exp 2 and 3 (Table 1). All imazamox treatments performed well in Exp 3, whereas the low rate did not appear to be adequate in Exp 2.

Weed counting and dry weight measurements

The decrease in dicotyledon weed number was noteable, when the highest dose of imazamox (60 g ai ha^{-1} + surfactant) was used in Exp 2 (Table 2). The application of imazamox inhibits the function of acetolactate synthase in plants relatively fast, resulting in rapid growth retardation. Despite of the rapid growth retardation, the appearance of lethal symptoms and mortality in sensitive plants takes place slowly (Dekker and Duke 1995). Due

Table 1. Effect of imazamox on visual assessments of oilseed rape injury and weed control.

Treatment	Phytotoxicity 1	Phytotoxicity 2	Phytotoxicity 3	Effect on weeds
Tuusula 2002				
Untreated	0	0	ND	ND
60 g ai ha^{-1}+s	5	0	ND	ND
40 g ai ha^{-1}+s	5	0	ND	ND
30 g ai ha^{-1}+s	5	0	ND	ND
30 g ai ha^{-1}	5	0	ND	ND
Jokioinen 2002				
Untreated	0	0	0	0
60 g ai ha^{-1}+s	3	0	0	86
40 g ai ha^{-1}+s	3	0	0	83
30 g ai ha^{-1}+s	3	0	0	70
30 g ai ha^{-1}	0	0	0	65
Helsinki 2003				
Untreated	0	0	0	0
60 g ai ha^{-1}+s	0	0	0	88
40 g ai ha^{-1}+s	0	0	0	83
30 g ai ha^{-1}+s	0	0	0	85
30 g ai ha^{-1}	0	0	0	85
Jokioinen 2003				
Untreated	0	0	0	ND
60 g ai ha^{-1}+s	3	3	0	ND
40 g ai ha^{-1}+s	3	3	0	ND
30 g ai ha^{-1}+s	3	3	0	ND
30 g ai ha^{-1}	2	2	0	ND

s = surfactant 0.25% (v/v), ND = no data
Phytotoxicity = effect on *B. napus* L.: scale 0–100, 0 = no injuries 100 = all dead
Tuusula 2002: phytotoxicity1 = 3DAT, phytotoxicity2 = 13DAT
Jokioinen 2002: phytotoxicity1 = 1DAT, phytotoxicity2 = 6DAT, phytotoxicity3 =13DAT
Helsinki 2003: phytotoxicity1 = 7DAT, phytotoxicity2 = 14DAT, phytotoxicity3 = 21DAT
Jokioinen 2003: phytotoxicity1 = 2DAT, phytotoxicity2 = 7DAT, phytotoxicity3 = 14DAT
Effect on weeds: scale 0–100, 0 = untreated 100 = all dead
Jokioinen 2002: effect on weeds = 13DAT
Helsinki 2003: effect on weeds = 14DAT

to this, the weed counting in Exp 1 was made too early, only 9 DAT. The counting of the weed number of three selected weed species showed, that imazamox has a good effect against *C. album*, but not against *V. arvensis* or *L. communis* (Table 2). Total weed dry weight tended to decrease for all imazamox treatments (Table 3). In general, low application rate (30 g ai ha^{-1}) can be recommended, if additive surfactant is used.

More detailed analysis on the abundance of different weed species and on the effect of imazamox on weeds was done in Exp 2 and 4. These two experiments differed significantly in weed number; in Exp 2 the total number was high (Table 4), while numbers were low in Exp 4 (Table 5). The most common weed species were *C. album* (Exp 2) (Table 4) and *Lamium purpureum* (Exp 4) (Table 5). In both experiments, imazamox was effective against *C. album, Stellaria media* and with a higher dosage against *Galium spurium* (Tables 4 and 5). Furthermore, the effect of imazamox against *Thlapsi arvense* was good in Exp 4. Imazamox efficacy was poor for example against *L. purpureum, L. communis, Fumaria officinalis, Fallopia convolvulus, Erysimum cheiranthoides* and *Polygonum* species. *Galeopsis bifida* did not suffer

Table 2. The estimated means of the number (no m^{-2}) of the selected weed species, *Chenopodium album* (CHEAL), *Viola arvensis* (VIOAR) and *Lapsana communis* (LAPCO); the number of total weed 34–38 DAT (Jokioinen 2002, Helsinki 2003 and Jokioinen 2003) and 9 DAT (Tuusula 2002). Numbers in italic refer to the P-values where the different rates of imazamox have been compared to the untreated plot.

Treatment	CHEAL	*P-value CHEAL*	VIOAR	*P-value VIOAR*	LAPCO	*P-value LAPCO*	Total weeds	*P-value Total weeds*
Tuusula 2002								
Untreated	47		239		34		339	
60 g ai ha^{-1}+s	38	*0.46*	233	*0.92*	19	*0.28*	310	*0.74*
40 g ai ha^{-1}+s	30	*0.19*	195	*0.53*	22	*0.37*	261	*0.40*
30 g ai ha^{-1}+s	18	*<0.05*	237	*0.98*	19	*0.28*	295	*0.62*
30 g ai ha^{-1}	33	*0.28*	152	*0.24*	17	*0.22*	213	*0.19*
Jokioinen 2002								
Untreated	926		ND		5		1139	
60 g ai ha^{-1}+s	85	*<0.05*	ND		5	*0.88*	187	*<0.05*
40 g ai ha^{-1}+s	225	*<0.05*	ND		5	*1.00*	391	*<0.05*
30 g ai ha^{-1}+s	379	*<0.05*	ND		5	*0.88*	591	*<0.05*
30 g ai ha^{-1}	679	*<0.05*	ND		7	*0.55*	887	*<0.05*
Helsinki 2003								
Untreated	9		6		ND		27	
60 g ai ha^{-1}+s	0	*<0.05*	4	*0.35*	ND		5	*<0.05*
40 g ai ha^{-1}+s	1	*<0.05*	4	*0.48*	ND		7	*<0.05*
30 g ai ha^{-1}+s	1	*<0.05*	5	*0.64*	ND		8	*<0.05*
30 g ai ha^{-1}	4	*<0.05*	5	*0.64*	ND		10	*<0.05*
Jokioinen 2003								
Untreated	32		ND		4		134	
60 g ai ha^{-1}+s	0	*<0.05*	ND		2	*0.17*	34	*<0.05*
40 g ai ha^{-1}+s	1	*<0.05*	ND		1	*0.07*	51	*<0.05*
30 g ai ha^{-1}+s	2	*<0.05*	ND		1	*0.07*	67	*<0.05*
30 g ai ha^{-1}	4	*<0.05*	ND		2	*0.13*	77	*<0.05*

s = surfactant 0.25% (v/v), ND = no data

from imazamox treatment in Exp 1 (data not shown).

Yield and chemical analysis

Seed yield (kg ha^{-1}) varied significantly between both years and locations and thus each year and location is analyzed, separately. Herbicide treatments resulted in modest differences in yield and seed purity (Table 6). Generally, in cases when the herbicide treatment significantly increased yield (Exp 2), an increase in seed purity was also noteable. In Exp 1 the seed yield between treatments did not differ significantly from each other; this was due to the luxuriant vegetation of oilseed rape, so that the weeds could not compete with oilseed rape. In Exp 2 the total number of weeds (Table 2) was high resulting in a marked yield decrease in the control treatment (399 kg ha^{-1}) (Table 6). In Exp 2 the best yield result, 1210 kg ha^{-1}, was achieved when treated with 60 g ai ha^{-1} imazamox + surfactant. All treatments differed significantly from the untreated control. The seed purity in the untreated control was only 78.9%, wheras it was between 99 and 100% for all imazamox treatments. There was significantly lower weed pressure in Exp 3 (Table 2) than in Exp 2 and 4 and thus, no effect on yield was observed except when treated with 40 g ai ha^{-1} imazamox + surfactant. In Exp 4, where the total number of weeds was approximately four-fold compared to Exp 3, notably higher yield was measured in nearly all herbicide application than in untreated control.

Table 3. The estimated means of the dry weight (g m^{-2}) of the selected weed species, *Chenopodium album* (CHEAL), *Viola arvensis* (VIOAR) and *Lapsana communis* (LAPCO); the dry weight of total weed 34–38 DAT (Jokioinen 2002, Helsinki 2003 and Jokioinen 2003)) and 9 DAT (Tuusula 2002). Numbers in italic refer to the P-values where the different rates of imazamox have been compared to the untreated plot.

Treatment	CHEAL	P-value CHEAL	VIOAR	P-value VIOAR	LAPCO	P-value LAPCO	Total weeds	P-value Total weeds
Tuusula 2002								
Untreated	13.95		8.91		6.05		36.3	
60 g ai ha^{-1}+s	2.95	*<0.05*	6.92	*0.40*	1.62	*<0.05*	14.4	*<0.05*
40 g ai ha^{-1}+s	2.62	*<0.05*	5.35	*0.15*	1.36	*<0.05*	10.2	*<0.05*
30 g ai ha^{-1}+s	1.51	*<0.05*	6.49	*0.31*	1.23	*<0.05*	11.7	*<0.05*
30 g ai ha^{-1}	2.85	*<0.05*	5.23	*0.14*	1.45	*<0.05*	10.7	*<0.05*
Jokioinen 2002								
Untreated	296.9		ND		0.6		326.3	
60 g ai ha^{-1}+s	4.8	*<0.05*	ND		0.4	*0.76*	9.7	*<0.05*
40 g ai ha^{-1}+s	12.9	*<0.05*	ND		0.8	*0.61*	21.8	*<0.05*
30 g ai ha^{-1}+s	28.7	*<0.05*	ND		0.4	*0.68*	39.8	*<0.05*
30 g ai ha^{-1}	58.2	*<0.05*	ND		0.9	*0.54*	70.6	*<0.05*
Helsinki 2003								
Untreated	7.03		0.11		ND		22.64	
60 g ai ha^{-1}+s	0.00	*<0.05*	0.04	*0.25*	ND		0.12	*<0.05*
40 g ai ha^{-1}+s	0.02	*<0.05*	0.03	*0.22*	ND		1.10	*<0.05*
30 g ai ha^{-1}+s	0.02	*<0.05*	0.10	*0.93*	ND		3.96	*<0.05*
30 g ai ha^{-1}	0.05	*<0.05*	0.07	*0.50*	ND		5.71	*<0.05*
Jokioinen 2003								
Untreated	17.6		ND		0.8		39.0	
60 g ai ha^{-1}+s	0.0	*<0.05*	ND		0.3	*0.18*	1.6	*<0.05*
40 g ai ha^{-1}+s	0.0	*<0.05*	ND		0.2	*0.13*	3.4	*<0.05*
30 g ai ha^{-1}+s	0.1	*<0.05*	ND		0.2	*0.10*	3.9	*<0.05*
30 g ai ha^{-1}	0.2	*<0.05*	ND		0.1	*0.09*	4.9	*<0.05*

s = surfactant 0.25% (v/v), ND = no data

Chemical analysis of oil quality was carried out for Exp 1 and 3. Imazamox had no effect on any of the quality parameters (data not shown). However, due to a lack of replicates in the chemical analyses (pooled samples), no measure of variability was possible and a discussion of possible treatment effect differences is not plausible.

Discussion

In this study, we found that imazamox was suitable for controlling weeds in IMI-resistant oilseed rape in Finland. Phytotoxicity symptoms in Canadian oilseed rape cultivars treated with imazamox were transient. These symptoms mainly consisted of chlorosis a few days after the treatment, especially in the treatments with surfactant. None of the imazamox treatments consistently reduced oilseed rape yields. Harker et al. (2000) have also indicated that imazethapyr/imazamox treatment did not lead to noteable crop injuries in oilseed rape. Based on the visual observations and crop yield results, it can be concluded, that the herbicide doses used in the trials, did not have a negative effect on the growth of *B. napus*. The highest dose with a surfactant gave the best result in controlling weeds. Also, the lower doses with a surfactant sufficiently controlled the most sensitive species. Even if the herbicide itself contains a surfactant, the additive improved the effect of imazamox especially in Exp 2 and 4.

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Table 4. Effect of imazamox on the number (no m^{-2}) (a) and the dry weight (g m^{-2}) (b) of the most abundant weed species in Jokioinen 2002. Numbers in italic refer to the percentage of weed number or dry weight compared to control.

Treatment	cheal	steme	galsp	lampu	erych	polco	polss	fumof	lapco	gaess	Oth.	Total
a) the number of weeds (no m^{-2})												
Untreated	926	93	17	49	12	6	6	6	5	12	7	1139
60 g ai ha^{-1}+s	85	16	2	29	7	10	4	5	5	8	16	187
	9	*17*	*12*	*59*	*58*	*167*	*67*	*83*	*100*	*67*		*16*
40 g ai ha^{-1}+s	225	45	7	38	12	10	3	8	5	11	27	391
	24	*48*	*41*	*78*	*100*	*167*	*50*	*133*	*100*	*92*		*34*
30 g ai ha^{-1}+s	379	83	13	45	11	6	6	7	5	11	25	591
	41	*89*	*76*	*92*	*92*	*100*	*100*	*117*	*100*	*92*		*52*
30 g ai ha^{-1}	679	65	17	52	13	9	9	9	7	14	13	887
	73	*70*	*100*	*106*	*108*	*150*	*150*	*150*	*140*	*117*		*78*
b) the dry weight of weeds (g m^{-2})												
Untreated	296.9	15.4	1.6	2.7	0.9	1.0	1.0	1.6	0.6	4.2	0.4	326.3
60 g ai ha^{-1}+s	4.8	0.5	0.0	1.0	0.4	0.9	0.3	0.1	0.4	0.7	0.5	9.7
	2	*3*	*0*	*37*	*44*	*90*	*30*	*6*	*67*	*17*		*3*
40 g ai ha^{-1}+s	12.9	0.7	0.2	1.7	0.9	1.0	0.3	0.3	0.8	1.0	2.0	21.8
	4	*5*	*13*	*63*	*100*	*100*	*30*	*19*	*133*	*24*		*7*
30 g ai ha^{-1}+s	28.7	1.8	0.5	2.3	0.7	0.5	0.5	0.3	0.4	1.6	2.5	39.8
	10	*12*	*31*	*85*	*78*	*50*	*50*	*19*	*67*	*38*		*12*
30 g ai ha^{-1}	58.2	2.8	0.9	2.5	0.6	0.3	0.7	0.6	0.9	1.8	1.3	70.6
	20	*18*	*56*	*93*	*67*	*30*	*70*	*38*	*150*	*43*		*22*

s = surfactant 0.25% (v/v)

cheal = *Chenopodium album,* steme = *Stellaria media,* galsp = *Galium spurium,* lampu = *Lamium purpureum,* erych = *Erysimum cheiranthoides,* polco = *Fallopia convolvulus,* polss = *Polygonum* spp., fumof = *Fumaria officinalis,* lapco = *Lapsana communis,* gaess = *Galeopsis* spp., Oth.= other weeds, Total = total number or dry weight of weeds

The Canadian IMI-resistant cultivars were relatively late-maturing and only matured in this study due to higher than normal temperature accumulation at our study site. For example, in Jokioinen in 2002, the effective temperature sum was 1323.7°C at harvesting time, which is 270°C more than the average effective temperature sum. However, in Finland, the yield stability of these late-maturing cultivars may be poor under more normal conditions. Therefore, the IMI-resistance should be transferred to oilseed rape cultivars which are well adapted to conditions in Finland.

The most difficult weed species in oilseed field in Finland are *C. album* and *G. spurium* (Salonen 2002) and according to this study, imazamox had a very good effect on them. Harker et al. (2000) have also reported about the good effect of imazamox against these species. The competition of weeds with oilseed rape depends upon the establishment of the crop and on the weather during early spring (Knott 1990). Cold weather and drought can delay the emergence of oilseeds, while *C. album* can utilize these growing conditions and compete well with the oilseed rape (Raatikainen et al. 1971, Weaver et al. 1988). The effect of imazamox against *S. media* was good or moderate, whereas the effect on *V. arvensis, L. communis* and *F. convolvulus* was not sufficient. In addition to the broadleaved weed species, imidazolinones control many annual grass species, including *Avena fatua* (Harker et al. 2000, Monaco et al. 2002). In this study only broadleaved weeds were assessed. The

Table 5. Effect of imazamox on the number (no m^{-2}) (a) and the dry weight (g m^{-2}) (b) of the most abundant weed species in Jokioinen 2003. Numbers in italic refer to the percentage of weed number or dry weight compared to control.

Treatment	cheal	galsp	lampu	steme	lapco	fumof	thlar	Oth.	Total
a) the number of weeds (no m^{-2})									
Untreated	32	31	35	21	4	3	4	4	134
60 g ai ha^{-1}+s	0	3	23	3	2	0	0	3	34
	0	*10*	*66*	*14*	*50*	*0*	*0*		*25*
40 g ai ha^{-1}+s	1	8	34	3	1	1	0	3	51
	3	*26*	*97*	*14*	*25*	*33*	*0*		*38*
30 g ai ha^{-1}+s	2	13	36	7	1	1	0	7	67
	6	*42*	*103*	*33*	*25*	*33*	*0*		*50*
30 g ai ha^{-1}	4	14	47	6	2	1	0	3	77
	13	*45*	*134*	*29*	*50*	*33*	*0*		*57*
b) the dry weight of weeds (g m^{-2})									
Untreated	17.6	7.9	3.6	7.1	0.8	0.4	0.8	0.8	39.0
60 g ai ha^{-1}+s	0.0	0.1	1.0	0.1	0.3	0.0	0.0	0.1	1.6
	0	*1*	*28*	*1*	*38*	*0*	*0*		*4*
40 g ai ha^{-1}+s	0.0	0.5	2.1	0.2	0.2	0.0	0.0	0.4	3.4
	0	*6*	*58*	*3*	*25*	*0*	*0*		*9*
30 g ai ha^{-1}+s	0.1	0.8	2.0	0.4	0.2	0.0	0.0	0.4	3.9
	1	*10*	*56*	*6*	*25*	*0*	*0*		*10*
30 g ai ha^{-1}	0.2	1.2	2.7	0.3	0.1	0.0	0.0	0.4	4.9
	1	*15*	*75*	*4*	*13*	*0*	*0*		*13*

s = surfactant 0.25% (v/v)

cheal = *Chenopodiun album,* galsp = *Galium spurium,* lampu = *Lamium purpureum,* steme = *Stellaria media,* lapco = *Lapsana communis,* fumof = *Fumaria officinalis,* thlar = *Thlapsi arvense,* Oth. = other weeds, Total = total number or dry weight of weeds

symptoms of the susceptible weeds were chlorotic and later necrotic growing points, shortened internodes, and pigment changes, such as purpling and reddening (Monaco et al. 2002). Because imazamox does not kill the weeds immediately (Dekker and Duke 1995), weed biomass decreases more quickly than weed numbers. After imazamox restricts weed growth, the oilseed rape rapidly preempts light and nutrient resources to successfully compete with the weeds.

Until now, the most common herbicide controlling weeds in oilseed fields in Finland has been trifluralin (Ministry of Agriculture and Forestry 2003), soil-applied herbicide, used pre-emergence to control many annual grass and broadleaved weeds (BCPC 1997). Using post-emergence herbicides, such as imazamox, gives an opportunity to control weeds only when it is needed and thus avoid the unnecessary use of herbicides (Blackshaw et al. 1994).

Table 6. The estimated means of the seed yield (kg ha^{-1}), seed purity (%) and 1000 seed weight (g) in Tuusula 2002, Jokioinen 2002, Helsinki 2003 and Jokioinen 2003. Numbers in italic refer to the P-values where the different rates of imazamox have been compared to the untreated plot.

Treatments	Yield[a] kg ha^{-1}	*P-value Yield*	Seed purity %	*P-value Seed purity*	1000 seed weight[a] g	*P-value 1000 seed weight*
Tuusula 2002						
Untreated	3193		97.1		3.19	
60 g ai ha^{-1}+s	3130	*0.67*	99.7		3.03	
40 g ai ha^{-1}+s	3172	*0.89*	99.1		3.02	
30 g ai ha^{-1}+s	3210	*0.91*	99.8		2.92	
30 g ai ha^{-1}	3246	*0.72*	99.5		3.05	
Jokioinen 2002						
Untreated	399		78.9		3.57	
60 g ai ha^{-1}+s	1210	*<0.05*	99.5	*<0.05*	3.43	*0.12*
40 g ai ha^{-1}+s	1081	*<0.05*	99.4	*<0.05*	3.56	*0.87*
30 g ai ha^{-1}+s	983	*<0.05*	99.6	*<0.05*	3.52	*0.52*
30 g ai ha^{-1}	971	*<0.05*	99.0	*<0.05*	3.55	*0.82*
Helsinki 2003						
Untreated	2712		99.1		2.54	
60 g ai ha^{-1}+s	2574	*0.31*	99.5		2.35	
40 g ai ha^{-1}+s	2372	*<0.05*	99.4		2.49	
30 g ai ha^{-1}+s	2650	*0.64*	99.8		2.37	
30 g ai ha^{-1}	2577	*0.32*	99.8		2.40	
Jokioinen 2003						
Untreated	2092		97.7		3.04	
60 g ai ha^{-1}+s	2366	*<0.05*	98.6	*<0.05*	3.16	*0.08*
40 g ai ha^{-1}+s	2346	*<0.05*	98.4	*0.08*	3.11	*0.33*
30 g ai ha^{-1}+s	2284	*0.08*	98.0	*0.40*	3.07	*0.66*
30 g ai ha^{-1}	2433	*<0.05*	98.5	*<0.05*	3.12	*0.25*

s = surfactant 0.25% (v/v)

[a] in 9% moisture, ND = no data

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SELOSTUS

Imazamoxin vaikutus imidatsolinoni-resistentin kevätrapsin kasvustoon ja esiintyviin rikkakasveihin

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Imidatsolinonit (IMI:t) ovat herbisidejä, jotka ehkäisevät asetolaktaattisyntetaasi-entsyymin toimintaa. IMI:t tehoavat hyvin useisiin leveälehtisiin rikkakasveihin ja yksisirkkaisiin heiniin. Rapsi (*Brassica napus*) ei ole luonnostaan resistentti imidatsolinoneille, mutta rapsin IMI-kestävyyttä on voitu lisätä mutaatiojalostuksen avulla. IMI-resistenttejä rapsilajikkeita on ollut jo usean vuoden ajan markkinoilla etenkin Pohjois-Amerikassa. Tässä tutkimuksessa selvitimme, soveltuvatko IMI:t Suomen olosuhteissa käytettäviksi.

Tulostemme mukaan imidatsolinoni-käsittely (imazamox) ei alentanut IMI-resistentin rapsin satoa tai öljyn laatua. Käsittelyn jälkeisinä päivinä rapsissa esiintyi hieman kloroottisuutta, mutta se tasoittui muutamassa päivässä. Imazamox tehosi erittäin hyvin Suomen öljykasvipeltojen yleisimpiin ja taloudellisesti haitallisimpiin rikkakasveihin, jauhosavikkaan (*Chenopodium album*) ja peltomataraan *(Galium spurium)*, kun taas pelto-orvokkiin (*Viola arvensis*), linnunkaaliin (*Lapsana communis*) ja kiertotattareen (*Fallopia convolvulus*) imazamox ei tehonnut riittävästi. Tulosten perusteella voidaan sanoa, että IMI-resistentit lajikkeet ja imazamox ovat hyvä vaihtoehto Suomen öljykasvipeltojen rikkakasvien torjunnassa. Siksi IMI-kestävyys tulisi siirtää suomalaisiin, aikaisiin rypsi- ja rapsilajikkeisiin.