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REGULAR ARTICLE

Fatty acid and glucosinolate level in seeds of different types of winter oilseed rape cultivars (*Brassica napus* L.)

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ABSTRACT

Winter oilseed rape is today the most important oil crop in the European Union. Almost all of the oilseed rape production in Europe is based on zero erucic, low seed glucosinolate type (so-called 00-quality or canola-quality seed). Winter oilseed rape oil is ideal for human nutrition and for use as a biofuel. The aim of this study was to determine the variability of the major fatty acids and glucosinolates in seven winter oilseed rape cultivars of different types: open pollinated, composite hybrids and restored hybrids. During two crop seasons (2002-2003 and 2003-2004), varieties were tested in field trials in two locations in the Wielkopolskie region of Poland. Location affected oil and the glucosinolate contents (especially for progoitrin and alkenyl total). The mean oil concentration ranged from 44.5% (Borowo 2003) to 48.2% (Borowo 2004), with a high coefficient of heritability in the range of 0.57-0.89, respectively. The composite hybrids Kaszub and Pomorzanin and their maternal line CMS Samourai had the highest alkenyl glucosinolate levels. The cultivar Kronos had low levels of gluconapin, glucobrassicanapin, progoitrin, indolyl, and alkenyl total. The heritability coefficients for total alkenyl glucosinolate levels were high for all four studied environments. Fatty acid and glucosinolate levels in the different types of cultivars tested were typical for double low winter oilseed rape cultivars that have been sown in Poland and throughout Europe for 30 years.

Key Words: *oilseed rape (Brassica napus* L.*); different types of cultivars; fatty acid compositions; glucosinolate level.*

INTRODUCTION

Oilseed rape is becoming the second most common plant, after soybean, for the production of oil seeds and oil meal (protein source) and the third, after soybean and palm

kernel, as a vegetable source for edible oil. Winter oilseed rape is the most important oilseed crop in Poland and Europe. At present, double low quality winter oilseed rape, which is low in erucic acid (up to 2% in consumption seeds) and has low glucosinolate level (up to 25 μmol g^{-1} of seeds), is in commercial production in Poland. Mature oilseed rape seeds are rich in oil, reaching 45-50% of contents. The oil from 00-quality oilseed rape contains 60% monounsaturated oleic acid ($C_{18:1}$), 30% polyunsaturated fatty acids [20% linoleic acid ($C_{18:2}$), 10% linolenic acid ($C_{18:3}$)], 2.0% eicosenoic acid ($C_{20:1}$), 7.0% saturated fatty acids [mainly palmitic ($C_{16:0}$), and stearic acids ($C_{18:0}$)] and 1.0% other acids (Möllers, 2002).

Erucic acid-free oilseed rape oils are ideal for human nutrition and for use as a biofuel. A typical rapeseed oil with a 2:1 ratio of mono-unsaturated to polyunsaturated fatty acids fits perfectly with dietary recommendations. It is an excellent salad oil. The nutritional quality of rapeseed oil can be improved through the development of cultivars combining high oleic acid and low linolenic acid, so-called HOLL (Spasibionek, 2006; Wittkop, et al. 2009; and Federico and Federico, 2011). Although the meal from oilseed rape after oil extraction provides a protein-rich animal feed, it has a number of antinutritional components, such as glucosinolates, sinapate esters, phytic acid, tannins and crude fiber (Wittkop et al., 2009). Breeding programs have thus aimed at increasing the quality of the rapeseed meal, while simultaneously reducing antinutritional factors (Bartkowiak-Broda, 2011; Szydłowska-Czerniak, et al. 2011).

The aim of this study was to determine the variability of the major fatty acids and glucosinolates in different types of winter oilseed rape cultivars.

MATERIALS AND METHODS

PLANT MATERIALS AND FIELD TRIALS

The plant material used in this study comprised seven different varieties of winter oilseed rape: the open pollinated variety "Lisek" (Deutsche Saatveredelung GmbH, Lippstadt) and "Samourai" – a CMS *ogura* line of the Samourai cultivar [the maternal lines of the composite hybrid v. Synergy (Serasem)], four Polish composite hybrids "Kaszub", "Lubusz", "Mazur", and "Pomorzanin" (Plant Breeding Company Strzelce Ltd. Group PBAI), and one restored hybrid "Kronos" (Norddeutsche Pflanzenzucht, Hans-Georg Lembke KG, Hohenlieth). The CMS *ogura* Samourai variety was pollinated by neighbouring plots with fertile male plants. The varieties were tested in the 2002/2003 and 2003/2004 growing seasons. Field trials were conducted in four replicates of a randomized block design at the Wielichowo Zielęcin Experimental Station (52°10'N, 16°23'E) and at the Borowo Division of the Strzelce Plant Breeding Company Ltd (52°07'N, 16°46'E) (Wielkopolska region, Poland). The two locations differed slightly in their climatic conditions, soil types and previous crops (Table 1). Experimental cultivars were grown on 10 m^2 plots, at a density of 80 plants per m^2. Each plot consisted of four rows with a row-to-row distance of 30 cm and approximately 20 cm distance between plants within rows. Sowing dates were between the 24th and 28th August.

FATTY ACID COMPOSITION AND GLUCOSINOLATE CONTENT

After the harvest, the seeds from each replicate plot were analysed. Analyses of glucosinolates (in μmol g^{-1} seeds) (alkenyl: gluconapin, glucobrassicanapin, progoitrin, napoleiferin and total alkenyl glucosinolates; indolyl and 4 OH-glucobrassicin) were performed using gas chromatography of the silyl derivatives of desulfoglucosinolates (Michalski et al., 1995; and PN ISO 9167-1:1999, 1999). Oil in the seeds (in %) of winter oilseed rape was analyzed using the nuclear magnetic resonance (Newport Instruments Ltd.) (Krzymański, 1970b). Fatty acids (FA) composition (in %) ($C_{16:0}$ – palmitic, $C_{18:0}$ – stearic, $C_{18:1}$ – oleic, $C_{18:2}$ – linoleic, $C_{18:3}$ – linolenic and $C_{20:1}$ – eicosenoic) was analyzed using gas chromatography (Byczyńska and Krzymański, 1969; and PN-EN ISO 5508:1996, 1996).

Table 1. Soil characteristics in the two trial locations – Borowo and Zielęcin – in crop seasons 2002/2003 and 2003/2004

Soil characteristics	Borowo		Zielęcin	
	2002/2003	2003/2004	2002/2003	2003/2004
Soil quality	good quality arable soil	good quality arable soil	moderate quality arable soil	moderate quality arable soil
Soil pH	5.3	6.1	6.3	5.4
Previous crop	wheat	triticale	barley	barley
Soil type (origin)	loessial soil	loessial soil	brown soil	brown soil
Soil texture (cultivated layer)	loamy sand, sandy loam	loamy sand, sandy loam	loamy sand	loamy sand
Microelements content in mg·100 g^{-1} soil:				
P_2O_5	17.3	20.8	25.0	19.5
K_2O	16.5	23.0	15.0	17.3
Mg	5.1	5.1	4.5	5.7

STATISTICAL ANALYSIS

A three-way analysis of variance was carried out to determine the effects of cultivars, years and locations as well as their interactions: cultivars × years, cultivars × locations, years × locations and cultivars × years × locations on the variability of studied traits. The normal distributions of residuals from the fitted models for the phenotypic traits analyzed (oil content, fatty acid composition: $C_{16:0}$ – palmitic, $C_{18:0}$ – stearic, $C_{18:1}$ – oleic, $C_{18:2}$ – linoleic, $C_{18:3}$ – linolenic and $C_{20:1}$ – eicosenoic, content of gluconapin, glucobrassicanapin, progoitrin, napoleiferin, indolyl, 4 OH-glucobrassicin and total alkenyl glucosinolates) were tested using the Shapiro-Wilk normality test (Shapiro and Wilk, 1965). The coefficients of variation (Kozak et al., 2013) of the observed traits for each year and location as well as the broad-sense heritability coefficients (h^2) were calculated (Falconer and Mackay, 1996). Utilizing information on the variance of the residual term from the analysis of variance model, this coefficient of variation describes variation within the traits, disregarding the variability that comes from the sources of variation from the experiment. All statistical analyses were conducted with the statistical software package GenStat v. 7.1 (Payne et al., 2003).

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) indicated that cultivar main effects were significant for all the traits in the study, except for $C_{16:0}$, napoleiferin and indolyl (Table 2). The main effect of years was not significant for $C_{18:0}$, $C_{21:1}$ and napoleiferin (Table 2). The location main effect was not significant for $C_{18:3}$, gluconapin, glucobrassicanapin and napoleiferin (Table 2). The effects of cultivar × year interaction were significant for all traits, except for $C_{16:0}$, $C_{18:1}$, $C_{18:3}$, $C_{20:1}$, napoleiferin and indolyl (Table 2). The cultivar × location interaction was significant for $C_{18:0}$ and $C_{21:1}$ (Table 2). The year × location interaction was significant for oil content, $C_{16:0}$, $C_{18:0}$, gluconapin, glucobrassicanapin, progoitrin, 4 OH-glucobrassicin, and total alkenyl content (Table 2), whereas the cultivar × year × location interaction was significant only for oil content (Table 2).

Table 2. Mean squares from analysis of variance (ANOVA) for observed traits of winter oilseed rape (*Brassica napus* L.)

Source of variation	Degrees of freedom	Oil content	$C_{16:0}$ palmitic	$C_{18:0}$ stearic	$C_{18:1}$ oleic	$C_{18:2}$ linoleic	$C_{18:3}$ linolenic	$C_{20:1}$ eicosenoic	Gluconapin	Gluco-brassica-napin	Progoitrin	Napole-iferin	Indolyl	4 OH-gluco-brassicin	Total Alkenyl
Cultivar (C)	6	7.08***	0.154	0.228***	17.96**	8.024***	4.896***	0.251**	12.029***	0.864***	67.701***	0.023	0.0033	1.839***	158.82***
Year (Y)	1	34.67***	0.625*	0.110	31.60**	68.252***	31.862***	0.144	72.900***	4.556***	230.160***	0.020	0.0640**	2.093*	824.46***
Location (L)	1	4.65*	2.500***	1.560***	83.96***	60.148***	0.016	0.961***	0.306	0.105	7.183*	0.016	0.0303*	20.953***	13.34
C × Y	6	4.30***	0.065	0.107*	3.89	3.084*	0.544	0.124	8.007***	0.627***	34.636***	0.044	0.0057	1.637***	93.33***
C × L	6	1.01	0.077	0.112**	4.69	1.53	0.80	0.256**	0.404	0.096	1.495	0.035	0.0130	0.134	3.99
Y × L	1	303.27***	0.702*	1.024***	11.08	0.15	1.56	0.03	4.900***	1.350***	74.666***	0.049	0.0063	1.702*	159.60***
C × Y × L	6	2.29*	0.056	0.068	2.63	0.679	0.767	0.11	0.233	0.04	1.564	0.017	0.0079	0.203	3.13
Residual	132	0.95	0.111	0.036	4.52	1.395	0.482	0.077	0.343	0.047	1.613	0.034	0.0068	0.369	3.72

* P < 0.05, ** P < 0.01, *** P < 0.001; Oil content, all fatty acids (%); All glucosinolates (μmol $\cdot g^{-1}$ of seeds)

Table 3. Oil content (%) and fatty acids composition (%) in different types of winter oilseed rape varieties; means were calculated for a particular cultivar in a particular environment

Cultivar		Kaszub	Kronos	Lisek	Lubusz	Mazur	Pomorz-anin	Samourai	$\bar{x}$	cv [%]	h^2
Oil content [%]	B3#	45.28	45.16	44.51	45.05	44.20	45.03	43.12	44.52	0.43	0.76
	B4	49.45	47.41	46.94	49.45	48.45	48.18	48.89	48.20	0.30	0.89
	Z3	47.65	47.36	46.50	47.43	47.25	47.67	45.77	46.93	0.27	0.86
	Z4	45.17	45.29	44.85	46.38	45.30	45.00	44.46	45.10	0.45	0.57
	Mean	46.89	46.31	45.70	47.07	46.30	46.47	45.56	46.19	0.32	0.68
$C_{16:0}$ Palmitic	B3	4.90	4.98	4.71	4.53	4.55	4.60	4.68	4.73	1.54	0.48
	B4	4.45	4.59	4.38	4.33	4.38	4.45	4.60	4.47	1.00	0.53
	Z3	4.28	4.48	4.30	4.35	4.40	4.35	4.28	4.35	0.53	0.68
	Z4	4.23	4.38	4.53	4.20	4.28	4.28	4.39	4.36	1.71	0.29
	Mean	4.46	4.60	4.48	4.35	4.40	4.20	4.48	4.48	0.65	0.54
$C_{18:0}$ Stearic	B3	1.70	1.74	1.99	1.65	1.70	1.78	1.61	1.75	2.04	0.72
	B4	1.58	1.55	1.73	1.60	1.63	1.70	1.69	1.64	1.17	0.71
	Z3	1.30	1.41	1.46	1.65	1.28	1.30	1.33	1.39	2.14	0.73
	Z4	1.10	1.58	1.80	1.65	1.48	1.48	1.80	1.61	2.70	0.83
	Mean	1.20	1.57	1.74	1.64	1.52	1.56	1.61	1.60	1.24	0.79
$C_{18:1}$ Oleic	B3	60.33	59.99	63.05	61.70	60.82	59.83	61.64	61.20	0.99	0.42
	B4	61.00	61.39	63.39	63.15	62.08	63.15	63.62	62.62	0.48	0.68
	Z3	62.15	63.98	64.77	62.35	62.28	63.15	62.18	63.18	0.32	0.84
	Z4	62.28	63.00	64.89	62.45	62.88	62.92	64.55	63.54	0.34	0.81
	Mean	61.44	62.09	64.02	62.41	62.01	62.26	63.00	62.63	0.29	0.78
$C_{18:2}$ Linoleic	B3	21.65	21.39	19.29	20.60	21.28	21.18	21.68	20.94	1.44	0.63
	B4	20.52	20.36	19.23	19.38	19.18	18.95	19.26	19.57	1.13	0.57
	Z3	19.90	19.24	18.50	19.98	20.65	19.62	20.45	19.65	0.60	0.89
	Z4	18.68	18.91	17.39	19.28	18.77	18.15	18.30	18.41	0.68	0.83
	Mean	20.19	19.98	18.60	19.81	19.97	19.48	19.92	19.64	0.60	0.78
$C_{18:3}$ Linolenic	B3	9.90	10.26	9.24	9.53	10.13	10.18	8.79	9.63	1.71	0.70
	B4	10.98	10.73	10.00	10.33	11.02	10.38	9.55	10.33	1.34	0.74
	Z3	9.58	9.14	8.80	9.80	9.90	9.73	9.63	9.41	0.59	0.91
	Z4	11.03	10.79	10.09	10.80	11.18	11.05	9.61	10.50	0.91	0.88
	Mean	10.37	10.23	9.53	10.11	10.56	10.33	9.39	9.97	0.69	0.87
$C_{20:1}$ Eicosenoic	B3	1.18	1.31	1.33	1.48	1.25	1.75	1.39	1.37	4.11	0.58
	B4	1.35	1.39	1.28	1.30	1.50	1.38	1.26	1.34	2.26	0.54
	Z3	1.88	1.45	1.58	1.58	1.28	1.53	1.61	1.55	3.85	0.55
	Z4	2.08	1.33	1.29	1.50	1.38	1.80	1.34	1.47	2.76	0.88
	Mean	1.62	1.37	1.37	1.46	1.35	1.61	1.40	1.43	1.72	0.73

B3 – Borowo 2003, B4 – Borowo 2004, Z3 – Zielęcin 2003, Z4 – Zielęcin 2004

$\bar{x}$ – mean value, cv – coefficient of variation, h^2 – heritability coefficient

Table 3 shows the phenotypic variation for oil content and fatty acid composition. The seed oil level of the cultivars differed between years and locations. Mazur and Kaszub – Polish composite hybrid cultivars – demonstrated the highest oil levels at Borowo 2004. The mean oil levels ranged from 44.5% (B3) to 48.2% (B4) with a high coefficient of heritability of 0.57 and 0.89, respectively (Table 3).

The oil level in mature winter oilseed rape seeds normally fluctuates around 45-50%. An increase in the oil content and seed oil yield of oilseed rape cultivars is among the major aims of present breeding programs. Wittkop et al. (2009) indicated that the complex genetic background and determinism of seed oil content in the complex polyploid *B. napus* is poorly

understood. Interactions among a large number of gene loci (QTL) are involved in determining seed oil content and a strong environmental (e.g. temperature, water and nutrient supply) modification of seed oil content has been observed (Nesi et al., 2008; and Friedt and Snowdon 2009). For this reason, increases in seed oil content have proven to be difficult to achieve in classical breeding programs. In this context, the identification and utilization of genes contributing to oil content via comparative QTL mapping in different genetic backgrounds could help to identify gene loci with a key influence on this complex trait in oilseed rape (Zhao et al., 2005; Delourme et al., 2006; and Wittkop et al., 2009).

All the tested cultivars presented typical fatty acid compositions for double low oilseed rape. The total saturated fatty acid levels ranged from 5.7% (Z3) to 6.5% (B3) (Table 3). The within-environment coefficient of variation for saturated fatty acid contents varied from 0.5% (Z3) for palmitic acid to 2.7% for stearic acid (Z4) (Table 3), suggesting rather small variation in saturated fatty acid contents. The coefficient of heritability was higher for stearic acid (Table 4). The within-environment coefficients of variation for polyunsaturated fatty acids were small, ranging from 0.3% (for oleic acid in Z3) to 1.7% (for linolenic acid in B3) (Table 4). These fatty acids demonstrated high heritability, with minimum of 0.42 (for oleic acid in B3) and maximum of 0.91 (for linolenic acid in Z3), which confirms the strong influence of growing and weather conditions and a length of vegetation period on the content of saturated and polyunsaturated acids in the seed oil. Also Spasibionek (2006; 2013) showed a strong influence of weather conditions on the content of oleic, linoleic and linolenic acids in the seed oil of winter oilseed rape mutants. Together with breeding for high oil level and seed oil yield, development of cultivars combining high oleic acid and low linolenic acid (HOLL) is one of the major current breeding aims for the quality improvement of oilseed rape.

Table 4 shows the phenotypic variation (content, mean value, coefficient of variation and heritability) for alkenyl (gluconapin, glucobrassicanapin, progoitrin and napoleiferin), total alkenyl and indolyl (indolyl, 4 OH-glucobrassicin) glucosinolate levels. These data show differences in glucosinolate levels among the tested cultivars that were due to variable growing conditions (environments). Variability of napoleiferin content was very large, especially in B4 (CV = 25.9%). Total alkenyl glucosinolates content ranged from 5.2 (Kronos in B4) to 20.8 μmol·g^{-1} of seeds (CMS Samourai in B3) with a low coefficient of variability 1.9–5.4% respectively. The highest alkenyl glucosinolate levels were observed in B3 for composite hybrids Kaszub and Pomorzanin and their maternal line CMS Samourai:

`16.10` μmol·g^{-1} of seeds (Kaszub in B3)
`14.55` (Pomorzanin in B3)
`20.80` (CMS Samourai in B3).

For all the studied environments, high coefficients of heritability for the most important alkenyl glucosinolate levels were estimated: gluconapin, glucobrassicanapin, progoitrin and total alkenyl glucosinolates (Table 4). Alkenyl glucosinolate-progoitrin level was marked by a medium coefficient of heritability (0.30 – 0.63) and also a medium coefficient of variability [11.3% (Z4) – 25.9% (B4)]. Indolyl glucosinolate content ranged from 0.08 (Lubusz in B4) to 0.23 μmol·g^{-1} of seeds (Kaszub, Mazur, CMS Samourai in B3 and Lubusz in Z3) and for 4-OH-glucobrassicin it varied from 2.00 (Lisek in Z3) to 4.35 μmol·g^{-1} of seeds (Mazur in B4). The coefficient of heritability for the indolyl glucosinolate levels varied from 0.37 (indolyl in Z4) to 0.86 (4 OH-glucobrassicin in Z4), with low coefficient of variability of 3.24-14.37, respectively. The results suggest that the fatty acids composition and glucosinolates levels significantly depend on both genetic and environmental factors, with a large influence derived from water, nutrient (e.g., sulfur) content and length of the growing season.

Table 4. Glucosinolates content in seeds (μmol·g^{-1} of seeds) of different winter oilseed rape varieties; means were calculated for a particular cultivar in a particular environment

		Cultivar									
		Kaszub	Kronos	Lisek	Lubusz	Mazur	Pomorza-nin	Samourai	$\bar{x}$	cv [%]	h^2
gluconapin	B3	4.25	2.24	2.70	3.58	3.25	4.13	5.56	3.62	2.48	0.97
	B4	3.43	1.38	1.68	2.15	2.00	2.65	1.44	1.92	2.62	0.97
	Z3	3.18	2.10	2.25	3.38	3.20	3.33	5.03	3.18	3.77	0.94
	Z4	3.13	1.50	2.04	2.15	2.43	2.70	2.18	2.18	5.89	0.73
	Mean	3.49	1.80	2.17	2.81	2.72	3.20	3.55	2.73	3.17	0.91
glucobrassicanapin	B3	1.23	0.66	0.89	0.78	0.78	1.33	1.44	1.01	4.76	0.89
	B4	0.88	0.35	0.58	0.45	0.43	0.58	0.36	0.49	2.67	0.97
	Z3	0.68	0.44	0.66	0.63	0.65	0.75	1.41	0.77	5.01	0.94
	Z4	0.83	0.41	0.73	0.53	0.58	0.78	0.63	0.62	6.65	0.69
	Mean	0.90	0.47	0.71	0.59	0.61	0.86	0.96	0.72	3.71	0.89
progoitrin	B3	10.25	5.20	5.83	7.40	7.65	8.75	12.90	8.19	2.05	0.98
	B4	7.43	3.43	3.70	4.33	4.70	5.65	3.95	4.43	3.01	0.94
	Z3	6.75	4.18	4.48	6.05	6.60	6.25	10.53	6.40	3.90	0.94
	Z4	7.85	3.81	4.71	5.08	6.25	6.10	5.68	5.37	5.50	0.76
	Mean	8.07	4.15	4.68	5.71	6.30	6.69	8.26	6.07	2.95	0.93
napoleiferin	B3	0.18	0.25	0.21	0.13	0.15	0.25	0.20	0.20	14.08	0.30
	B4	0.18	0.11	0.24	0.23	0.15	0.45	0.10	0.19	25.93	0.46
	Z3	0.10	0.16	0.16	0.10	0.10	0.15	0.19	0.15	12.06	0.40
	Z4	0.28	0.10	0.19	0.33	0.20	0.18	0.25	0.21	11.28	0.63
	Mean	0.18	0.16	0.20	0.19	0.15	0.27	0.18	0.19	7.79	0.40
indolyl	B3	0.23	0.14	0.14	0.18	0.18	0.23	0.23	0.18	5.39	0.77
	B4	0.15	0.11	0.14	0.08	0.23	0.13	0.10	0.13	14.37	0.46
	Z3	0.10	0.15	0.15	0.23	0.13	0.13	0.11	0.14	11.68	0.46
	Z4	0.10	0.13	0.09	0.15	0.13	0.10	0.11	0.11	9.93	0.37
	Mean	0.14	0.13	0.13	0.16	0.16	0.14	0.14	0.14	5.04	0.30
4 OH-gluco-brassicin	B3	3.05	3.23	2.86	3.50	2.98	3.38	3.14	3.14	3.26	0.43
	B4	3.48	3.05	2.69	2.65	4.35	3.88	2.88	3.16	4.57	0.74
	Z3	2.25	2.05	2.00	2.43	2.15	2.38	2.38	2.21	3.49	0.48
	Z4	3.43	2.64	2.21	2.25	3.13	3.35	2.28	2.64	3.24	0.86
	Mean	3.05	2.74	2.44	2.71	3.15	3.24	2.67	2.78	2.17	0.77
alkenyl total	B3	16.10	8.71	10.15	12.83	12.08	14.55	20.80	13.49	1.94	0.98
	B4	11.85	5.23	5.94	7.13	7.25	9.30	5.83	6.95	2.56	0.96
	Z3	11.22	7.28	7.92	10.45	11.03	10.93	17.55	10.91	3.47	0.95
	Z4	12.08	5.84	7.68	8.08	9.43	9.73	8.69	8.37	5.44	0.75
	Mean	12.81	6.76	7.92	9.62	9.94	11.13	13.22	9.93	3.01	0.92

A high level of glucosinolates in rapeseed meal reduces its palatability and acceptance by animals and can also lead to goitrogenic hypertrophy, liver and kidney problems (Walker and Booth, 2001). The low glucosinolate content was first identified in the Polish spring variety "Bronowski", which was then used for the breeding of 00-quality oilseed rape cultivars (Krzymański, 1970a). Lately bred double low winter oilseed rape/canola cultivars reveal remarkably low glucosinolate levels of 8-15 μmol g^{-1} of seed. Breeding efforts for further reduction of glucosinolate content are ongoing and targeted to reducing specific types of glucosinolates. Four QTL for seed glucosinolate content located on chromosomes A9, C2, C7 and C9 have been mapped in different *B. napus* studies (Uzunowa et al., 1995;

Howell et al., 2003; Sharpe and Lydiate, 2003; and Basunanda et al. 2007). Some spring canola breeding lines have been generated with almost no aliphatic glucosinolates. Hassan et al. (2008) suggest the possibility of a seed specific reduction of seed glucosinolate content via transgressive segregation in genetically diverse gene pools without changing levels in other plant tissues and organs. Nevertheless, glucosinolates and their degradation products play an important role in pest/disease defense reactions and stress resistance of rapeseed plants.

CONCLUSIONS

In summary, fatty acids and glucosinolate levels in the tested cultivars were typical of double low winter oilseed rape cultivars that have been widely cultivated for thirty years across the world. Breeding efforts with respect to meal quality are therefore aimed at the reduction of antinutritional components, without losing sight of breeding for increasing the oil content, quality and yield. According to Wittkop et al. (2009), a key to success is the availability or development of high-throughput screening and selection techniques for accurate phenotyping of all relevant seed oil and meal characteristics.

REFERENCES

Bartkowiak-Broda, I. (2011). Current status and future developments in rapeseed (*Brassica napus* L.) breeding. *Advances in Research and Technology of Rapeseed Oil, Monograph – part III*, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń, 11–20.

Basunanda, P., Spiller, T.H., Hasan, M., Gehringer, A., Schondelmaier, J., Lühs, W., Friedt, W., Snowdon, R.J. (2007). Marker-assisted increase of genetic diversity in a double-low seed quality winter oilseed rape genetic background. *Plant Breeding* 126, 581–587.

Byczyńska, B., Krzymański, J. (1969). Quick method to obtain fatty acid methyl ester for gas chromatography analysis. *Tłuszcze Jadalne* XIII, 108–114 (in Polish).

Delourme, R., Falentin, C., Huteau, V., Clouet, V., Horvais, R., Gandon, B., Specel, S., Hanneton, L., Dheu, J. E., Deschamps, M., Margale, E., Vincourt, P., Renard, M. (2006). Genetic control of oil content in oilseed rape (*Brassica napus* L.). *Theoretical and Applied Genetics* 113, 1331–1345.

Falconer, D.S., Mackay, T.F.C. (1996). *Introduction of quantitative genetics*. Addison Wesley Longman, Harlow, Essex.

Federico, L. I.-L., Federico, M. L. (2011). The genetics of *Brassica napus*. In: Schmidt, R., Bancroft, I. (Eds.): *Genetics and Genomics of the Brassicaceae, Plant Genetics and Genomics: Crops and Models 9*. Springer Science +Business Media, 291–312.

Friedt, W., Snowdon, R. (2009). Oilseed Rape. In: Vollmann, J., Rajcan, I. (Eds.): *Oil Crops, Handbook of Plant Breeding 4*. Springer Science +Business Media, 91–126.

Hassan, M., Friedt, N.M., Pons-Kühnemann, J., Freitag, K., Link, J., Snowdon, R.J. (2008). Association of gene-linked SSR markers to seed glucosinolate content in oilseed rape (*Brassica napus* ssp. *napus*). *Theoretical and Applied Genetics* 116, 1035–1049.

Howell, P.M., Sharpe, A.G., Lydiate, D.J. (2003). Homoeologous loci control the accumulation of seed glucosinolates in oilseed rape (*Brassica napus*). *Genome* 46, 454–460.

Kozak, M., Bocianowski, J., Rybiński, W. (2013). Note on the use of coefficient of variation for data from agricultural factorial experiments. *Bulgarian Journal of Agricultural Science* 19(4), 644–646.

Krzymański, J. (1970a). Chances of genetical improvement in chemical composition of winter rape (*Brassica napus*) seeds. *Plant Breeding, Acclimatization and Seed Production* 14(2), 95–133 (in Polish).

Krzymański, J. (1970b). Determination of oil and water content in oilseeds by NMR. *Oils, Detergents and Cosmetics* 14(4), 202–208 (in Polish).

Michalski, K., Kolodziej, K. and Krzymanski J. (1995). Quantitative analysis of glucosinolates in seeds of oilseed rape – effect of sample preparation on analytical results. *Proc. 9th International Rapeseed Congress, 4-7 July 1995*, Cambridge, UK, 3, 911–913.

Möllers, M. (2002). Development of high oleic acid oilseed rape. 8th International Conference for Renewable Resources and Plant Biotechnology NAROSSA® 2002, *Proceedings of NAROSSA 2002*, Magdeburg, published as CD-ROM.

Nesi, N., Delourme, R., Bregeon, M., Falentin, C., Renard, M. (2008). Genetic and molecular approaches to improve nutritional value of *Brassica napus* L. seed. *Comptes Rendus Biologies* 331, 763–771.

Payne, R.W., Murrey, D.A., Harding, S.A., Baird, D.B., Soutou, D., Lane, P.W. (2003). *GenStat for Windows (7th edition) Introduction*. VSN International Ltd., Oxford, England.

PN-EN ISO 5508:1996 (1996). *Vegetable and animal oils and fats. Analysis of methyl esters of fatty acids by gas chromatography*.

PN ISO 9167-1:1999 (1999). *Seeds of oilseed rape. Determination of the glucosinolate content. Method using high performance liquid chromatography*.

Shapiro, S.S., Wilk, M.B. (1965). An analysis of variance test for normality (complete samples). *Biometrika* 52, 591–611.

Sharpe, A.G., Lydiate, D.J. (2003). Mapping the mosaic of ancestral genotypes in a cultivar of oilseed rape (*Brassica napus*) selected via pedigree breeding. *Genome* 46, 461–468.

Spasibionek, S. (2006). New mutants of winter rapeseed (*Brassica napus* L.) with changed fatty acid composition. *Plant Breeding* 125, 259–267.

Spasibionek, S. (2013). Genetic and breeding study of winter oilseed rape mutants (*Brassica napus* L.) with changed fatty acid composition (in Polish). PBAI – NRI *Monographs and Dissertations*.

Szydłowska-Czerniak, A., Bartkowiak-Broda, I., Karlović, I., Karlovits, G., Szłyk, E. (2011). Antioxidant capacity, total phenolic, glucosinolates and colour parameters of rapeseed cultivars. *Food Chemistry* 127, 556–563.

Uzunova, M., Ecke, W., Weissleder, K., Röbbelen, G. (1995). Mapping the genome of rapeseed (*Brassica napus* L.). I. Construction of an RFLP linkage map and localization of QTLs for seed glucosinolate content. *Theoretical and Applied Genetics* 90, 194–204.

Walker, K.C., Booth, E.J. (2001). Agricultural aspects of rape and other *Brassica* products. *European Journal of Lipid Science and Technology* 103, 441–446.

Wittkop, B., Snowdon, R. J., Friedt, W. (2009). Status and perspectives of breeding for enhanced yield and quality of oilseed crops for Europe. *Euphytica* 170, 131-140.

Zhao, J., Becker, H., Zhang, D., Zhang, Y., Ecke, W. (2005). Oil content in an European × Chinese rapeseed population: QTL with additive and epistatic effects and their genotype-environment interactions. *Crop Science* 45, 51-59.